TOPICS OF THE MONTH

Power planning—the cross-roads

THERE is a marked difference between short-term and long-term planning—often described as tactics and strategy respectively. To the planner, both are important as long as they are not confused. It seems that we in this country are, unfortunately, in danger of confusing short-term and long-term aims in our planned power programme. The government recently reduced the nuclear power programme which it had originally put forward at the height of the fuel panic in 1957. At that time it was planned to erect nuclear power stations producing a total of 6,000 MW. by 1965. This target has now been postponed for five years, so that the same amount of nuclear capacity will be installed by 1970—the government has indicated that it only expects to see 3,000 MW. of nuclear capacity installed by 1966.

That there are tactical short-term advantages to be gained in cutting back the nuclear power programme cannot be denied. The surplus of coal and the lowering of world oil prices are both concomitant factors that must surely haunt the mind of any present-day minister of power. Yet, what are the long-term prospects for energy requirements? The third general report on the activities of the European Atomic Energy Community, Euratom, published recently, has tried to assess Europe's electricity requirements for the next twenty years, up to 1980. These requirements have been evaluated by extrapolating up to 1980 the function which expresses the relationship between electricity consumption and industrial production, at the same time making due allowance for the regular development of electricity consumption. These forecasts are made on the basis of a hypothetical annual rate of industrial expansion of 5.5% for the 1955-60 period and rates of 5% and 4% respectively for the periods 1960-70 and 1970-80 (it has been shown that these rates are in no way exaggerated and may be safely adhered to). The overall energy requirements for this period have been estimated as follows:

	1955	1960	1965	1970	1975	1980
10^6 TCE .. .. (millions of tons coal equivalent)	398	468	540	624	695	774
10^9 kWh.	185	264	370	518	701	950

The report draws a distinction between 'privileged' and 'non-privileged' sources of energy. The former include conventional fossil fuels; the 'non-privileged' sources are mainly nuclear energy. Naturally, total energy requirements will have to be met from both 'privileged' and 'non-privileged' sources, and it must be noted that the former are of necessity limited to the available deposits and their potential exploitation. From this the energy expectation for 'privileged' sources was determined and the following estimate of the future capacity of nuclear energy production for Euratom was forecast as:

	Share of nuclear energy	*Potential need for nuclear energy in 10^9 kWh.*	*Needs covered by nuclear energy in 10^9 kWh.*	*Net nuclear power to be installed (in MW.)*
Until 1965	—	14	14	2,000
1965–1970	$\frac{1}{3}$	105	53	7,600
1970–1980	$\frac{2}{3}$	342	228	32,600
		461	295	42,200

It must be assumed therefore that E.E.C. countries should have available by 1980 an installed capacity exceeding 40,000 MW. net. To understand the relative significance of this figure it is enough to realise that it implies a production of nuclear electricity by 1980 *over* 10% *higher than the scheduled total production of electricity for* 1960. This estimate, representing the most probable energy forecast must, of necessity, serve as a basis for long-term planning.

Great Britain does not belong to the European Economic Community and is only partially associated with Euratom, therefore the above figures do not directly refer to this country. Yet they are an indication—and a very strong one—that by reducing the nuclear power programme we run the risk of an overall power shortage in 20 years' time.

We have been informed by the U.K.A.E.A. that the cost of generating electricity from nuclear power will slightly exceed that from conventional fuel, but this again is not borne out by the Euratom report, which predicts a steady decrease in the cost of nuclear-generated electricity until by 1980 it becomes quite competitive with conventional power. Surely this can only be achieved by improving designs of existing power plant as well as investigating new kinds of plant. Euratom is in fact examining the possibilities of heavy water-moderated reactors, light water- and organic-moderated reactors, as well as the high-temperature gas-cooled graphite-moderated reactors (the latter in conjunction with the U.K.A.E.A.). By judiciously selecting the optimum designs of different types of reactors and ensuring a continuous source of supply of enriched uranium from either the U.S.A. or, if at all possible, Europe, one can indeed foresee a rapid decrease in nuclear generated electricity. Are these not portentous omens for our own power planners? Have we fully investigated what Great Britain's energy requirements will be by 1980, and if so, that we shall have sufficient deposits of fossil fuel to take into account the rate of industrial expansion that must surely occur?

Unless some agonising and fundamental re-thinking on this country's energy requirements for the next two generations is soon undertaken, carried out and adhered to, we shall indeed find ourselves in serious difficulties in the future—difficulties that will no longer be amenable to superficial tactical solutions.

Dust—boon or bane?

MAN has been acquainted with dust in the atmosphere since earliest times—but he only started to investigate it seriously towards the end of the last century. Although dust is considered a nuisance it adds much to the pleasure of life as well as having important effects on the weather. Thus dust particles form nuclei for condensation of water vapour when it is cooled to saturation point. Without dust the temperature of the water vapour would have to be far lower for condensation to take place and when it did take place the action would be violent. Meteorologists claim that dustless cooling can only take place in saturated air; this would result in heavy rainfall without clouds. The number of dust particles per unit volume of air varies according to time and place—experiments have shown that there is no such thing as completely dustless atmosphere.

It is fortunately realised nowadays that one of the greatest dangers of dust in enclosed buildings is in its explosive potential. Explosions can occur in any combustible dust or, indeed, any material that will burn or oxidise. When there is a proper air-dust mixture for rapid combustion, it is said to be within the explosive range. This range includes air-dust compositions from the lower to the upper limit. Below the lower limit flame propagation will not take place and above the upper limit there may be burning, but an explosion is not likely to occur in apparatus or enclosed spaces unless air is admitted. The lower and upper limit may be widely separated, depending upon the character of the dust. Moreover the degree of flammability of a dust depends upon its moisture content and its fineness; the drier and finer the dust the greater its flammability.

In this month's special feature on ' Dust Prevention and Control,' we have not alluded to the problem of dust explosions—this is of such a fundamental nature that it warrants separate treatment. However, the spectre of a potential explosion must surely haunt the mind of any manufacturer who does not lay sufficient stress on effective dust control.

Progress in fibres

THE annual report of Courtaulds Ltd. shows that the group profits of 1959/60 before tax were just over £21 million—the highest ever recorded by the group. This improvement was experienced almost without exception by all companies in the group, but particularly in the case of the fibres and chemicals division. Thus the benefits of operating the yarn mills at something near capacity have been reflected in increasing profits from these sources. The most notable acquisitions of the group during the past year have been Pinchin, Johnson & Associates Ltd. and Harbens Ltd. for which ordinary shares of Courtaulds Ltd. were issued in exchange.

The report points out that overall trading conditions in the U.K. over the past year were such as to encourage a revival in the textile industry. For example, the active conditions in the motor-car industry raised the demand for tyre fabrics. However, the persistent rise in the volume of imports of cloth from the Asian Commonwealth countries is causing increasing anxiety to Courtaulds especially as the rayon side of this industry is complementary to, and to some extent interchangeable with, cotton. A warning is given that should these imports continue to increase the benefits of the expensive reorganisation in the cotton industry will be lost and there will be little inducement to re-equip. Demand for high-tenacity viscose yarns from the tyre trade is now at a record level. It is expected, moreover, that an even stronger yarn will be available in small commercial quantities before the end of the present year. Production of the acrylic fibre *Courtelle* increased steadily throughout the year, and as more fibre became available it was found possible to widen the market. It is interesting to note that Courtaulds has for many years been a large manufacturer of sulphuric acid and carbon disulphide. Activity in this field is governed mainly by the offtake of chemicals for fibre production. With the acquisition of British Celanese Ltd., the group acquired considerable interests in the petrochemical field and now produces a wide range of products serving a very large number of industries. More recently the commercial possibilities of exporting complete process plants have been examined and as a result, four substantial contracts have been concluded with Soviet organisations for the supply and erection of two plants for the production of acetate yarn known as *Dicel*, one for the production of viscose tyre cord and one for the production of acrylic fibre *Courtelle*. The aggregate value of these contracts is close to £20 million.

Hydrodynamics research

THE causes of energy losses in centrifugal pumps have been thoroughly investigated by the British Hydrodynamics Research Association. Leakage flow through one neck ring was measured on a pump under running conditions and found to be 2% of pump delivery. This leakage flow could be prevented by means of pressure balancing, but the efficiency of the pump then only rose by a fraction of this amount. For some time the B.H.R.A. has used air testing for its work on the flow in centrifugal pumps, because this method offers considerable economic and sometimes experimental advantages. At moderate speeds the Reynolds Number of an air test is restricted to about one-fifth of that when using water, and there are also some slight compressibility effects. Because of these effects there is some doubt as to whether results of air testing are truly representative of the performance when pumping water. In order to clarify this matter, a series of careful measurements are being taken in collaboration with the National Engineering Laboratory on the same 6-in. pump using both air and water. The air tests have now been completed and an appreciable variation in efficiency was found over a range of speeds ranging from 1,500 to 3,500 r.p.m.

Other research carried out at the B.H.R.A. is on the errors in orifice-plate flow-meters caused by bad

approach velocities, and the development of a universal flow straightener has been completed and is currently being tested at the N.E.L. at much higher Reynolds Numbers than could be achieved at the B.H.R.A. On the whole, it appears that the dangers of upstream pipe bends causing errors in flow measurement may be exaggerated.

On the other hand, a single swirl, such as may appear at a pump discharge, can have serious effects even when long settling lengths of straight pipe are used. Although approach velocity distribution is the chief cause of errors in orifice-plate discharge coefficients, it appears that excessive turbulence levels also have an effect.

Experimental work has now been completed on the study of the influence of size distribution on the flow-characteristics of liquid/solid mixtures where the solid particles are larger than about 100 mesh. For graded materials the excess loss has been demonstrated to be a function of particle drag coefficient, and it has been found possible for a material of mixed size distribution to define a mean drag coefficient giving an adequate correlation of experimental results.

Rising oil consumption

THE consumption of petroleum products is one more sign of the steady industrial expansion in Britain during the past year. Following a record demand in 1959, newly issued figures relating to the first quarter of the present year show a further substantial rise in requirements. Total deliveries of just over 11 million tons for the three months were well over 20% higher than those for the same period of 1959. Greater requirements of heavy fuels for industry, enhanced demand for burning oil and increasing deliveries of raw materials for the manufacture of petrochemicals, all contributed to the record total. Nevertheless, the most significant item was a 14% rise in the use of lubricants—possibly reflecting the greater production and use of motor vehicles.

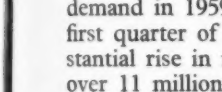
It is significant to note that demand for petroleum products in Britain during the past decade has trebled. Immediately before the second world war the U.K. crude oil refining capacity was less than 2 million tons p.a., although production of finished products was somewhat greater because a number of plants operated on ' topped crude '. Ten years later there was little change, capacity having been increased to about 2.5 million tons p.a. during the war. Since 1948, however, a large and important refining industry has been created which at present is capable of handling over 40 million tons of crude oil p.a. This can well compete with any other country, apart from the U.S.A. and the U.S.S.R. It is needless to state that the operation of oil refineries is of considerable economic benefit to this country. Apart from the saving in foreign exchange due to importing crude oil in place of refined petrol there has been a substantial revenue —running up to £100 million in recent years—from exports of refined products. In fact, had it not been for the vast activities of these refineries, the increasing demand for petroleum products might well have caused considerable balance of payment difficulties.

Foam prevention—end of the problem?

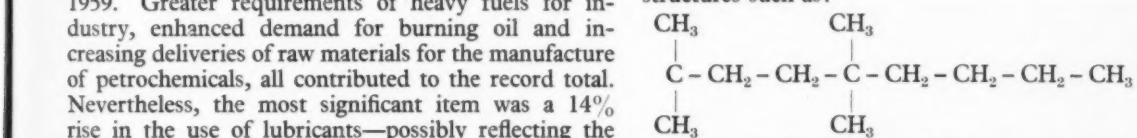
AT the recent annual conference of Sewage Purification the problem of detergent removal from sewage and foaming on rivers was discussed. The existence of this problem was first recognised in 1948 when white foam was noticed in aeration plants at sewage works, river weirs and canal locks. It must be remembered that the use of synthetic detergents has trebled between 1949 and 1953 when the Jephcott Committee was set up by the Ministry of Housing and Local Government. Following its report, a Standing Technical Committee on synthetic detergents was appointed to advise and facilitate research on this problem. This research has followed the recommendation that manufacturers should investigate the feasibility of producing efficient washing products based on materials which can be readily oxidised and eliminated, and will not cause persistent foaming during sewage treatment by available methods.

In the *Manufacturing Chemist*, May 1960, page 185, it was pointed out that several years ago C. Hamilton, senior chemist of the Metropolitan Water Board, found that alkyl benzene sulphonates are more readily decomposed by bacteria if the alkyl part of the molecule is a simple straight chain configuration rather than a more complex branched pattern.

In other words, compounds with structures such as:



were more likely to be biologically soft than those with structures such as:



This observation has been followed up and the Shell Chemical Co. have produced a dodecyl benzene with a relatively straight side chain which in the laboratory was destroyed by sewage processes to the extent of 94% compared with 68% for the old material. The new detergent base—*Dobane* JN—has been tested in the Luton and Harpenden areas since August 1958. However, in spite of the co-operation of detergent manufacturers it has only been possible to replace 70% of the detergents used in the area with products based on the new material. Nevertheless, there has been appreciably less foam on the rivers—the Lee and its tributaries—which supply London with a lot of its water. It is interesting to note from the third Progress Report of the Standing Technical Committee on synthetic detergents published recently, that these experiments were conducted secretly for fear that the public would refuse to buy the new products, that are otherwise identical with the old.

It is reassuring to know that this serious problem is being tackled in such a fundamental manner, and we can only hope that as soon as all the tests have been completed satisfactorily the government will not hesitate to introduce the requisite legislation.

Is bismuth radioactive?

THIS question occurred to us when we examined a new table of elements including all known isotopes, recently published by Fairey Engineering Ltd. The elements are arranged in ascending order of atomic numbers and the stable isotopes are indicated as green squares, while the unstable isotopes are indicated as red squares. It can be seen from this table that every element has both stable and unstable isotopes up to and including lead ($Z = 82$), with the exception of promethium $Z = 61$, europium $Z = 63$, gadolinium $Z = 64$, terbium $Z = 65$ and dysprosium $Z = 66$ which only have unstable isotopes. At atomic numbers exceeding 82 all elements have red squares—it would seem to include bismuth $Z = 83$, which has 17 isotopes ranging from 198 to 214. This was quite astounding to us and shocked our sense of metallurgy—was not bismuth metal commonly used, and how could this be so if it were unstable?

Further researches revealed that it was indeed radioactive. Reference to the table of nuclides from 'Nuclear and Radio-chemistry' by G. Friedlander and J. W. Kennedy, Chapman Hall Ltd., 1955, showed that bismuth isotopes range from 198 to 215. The common metal bismuth exists in the form of the isotope 209 with a half-life of about 2×10^{17} years, the form of decay being by alpha rays. To all intents and purposes this isotope is therefore stable since the decay is clearly infinitessimal. We consulted a well-known radio-chemist who offered a similar explanation, and calculated that the emission rate of 1 g. bismuth was approximately 2 alpha particles per day. This, of course, raises the further question whether there is a clear and distinct border-line between stable and unstable isotopes or whether all isotopes are unstable—only some more so than others. Nowadays infinitessimal rates of decay can be detected with improved measuring equipment. Will further improvement in such equipment resolve this question? Perhaps readers would like to comment on this.

Nuclear progress in Australia

AT the beginning of this year the Australian Atomic Energy Commission's research reactor HIFAR was taken up to full power after two years of calibration and testing. This was disclosed recently by Senator Spooner, Australian Minister of National Development. The reactor is primarily used for testing materials in combinations that might occur in other reactors suitable for Australian requirements. Senator Spooner admitted that Australia is at the moment not devising any plans for nuclear power because of unexpected developments in this field. Most coal-producing countries now have surpluses, and developments in coal mining and power house construction have brought down the cost of generating electricity from coal to quite a remarkable extent. At the same time, of course, a world surplus of oil has emerged and oil is competing with coal in many cases. It is therefore expected that Australia will wait at least a decade before deciding which type of nuclear power will be best suited to her conditions.

This does not indicate that by then nuclear power will be competitive with all other forms of power, but there are areas in Australia where the natural fuel resources for power generation are non-existent, and suitable reactors could be evolved there for providing power at economic rates.

The expansion in world nuclear power programmes has naturally reacted on the market for uranium. There are now five uranium producers in Australia—one Commonwealth enterprise at Rum Jungle, one state enterprise in South Australia and three other companies. Rum Jungle, launched under almost emergency conditions, has now settled down to smooth production after early teething troubles. The main concern of the Australian government is to discover further ore within reasonable reach of treatment plants to support future operations.

It should be added that Australian nuclear research owes much to co-operation received from overseas. Bilateral agreements have been made with the United Kingdom, United States and Canada. In addition, Australia plays an active part in the International Atomic Energy Agency.

Banking in Alabama

THE letters appearing on an editor's desk are not always complaints from enraged authors or contemptuous readers. From time to time letters arrive reflecting the lighter side of life. The following is an extract from a communication which we recently received from one of our contributors in the 'deep South'.

'A real honest-to-goodness cheque from Merrie England creates quite a little excitement when we take it proudly into a bank here in back-country Alabama. First, the teller looks at me suspiciously. Then he notes that the cheque on Barclay's Bank is not long and narrow like ours but more nearly square in configuration. At that point he feels pretty sure that I've forged the thing myself. Then he tosses the cheque in the air and lets it flutter down on his marble counter. There is no familiar bell-like tone as one hears when he flips a silver half-dollar and listens for the ringing sound that stamps it as genuine. The teller is about to ring for the armed uniformed guard at the door when he remembers the " bite " test, used to distinguish silver from soft-metal counterfeit coins. So he nibbles at a corner of Barclay's cheque, doesn't like the taste, and is just beckoning the guard when I say: " If you'll accept the cheque on probation, subject to examination, and give me a receipt——". So, he puts the cheque through for collection (which doesn't obligate the bank in any way), and after the cheque has been sent to New York, to Washington to the White House, back to New York, then to Tuscaloose, and finally back to Barclay's Bank in London, I get the money from which has been deducted " two bits " (25 cents), which seems to be the Federal amusement tax. When the government has collected enough two bits it is able to buy gasoline to send another plane over Russia for the Bolsheviks to shoot down'

Dust Control and Prevention

Until not so long ago the problem of dust formation accompanying many industrial processes was considered disagreeable but not sufficiently serious to warrant particular attention. This attitude of mind was rapidly changed when it was clearly shown that dusts form both health and explosive hazards. The coal industry is undoubtedly one of the industries most concerned with dust control, and the author, who is on the staff of the Mining Research Establishment, has been occupied with this problem for many years. This article discusses dust formation and its relation to particle size—a distinction being drawn between suppression and control of dust formation. By describing the characteristics of ventilation and air-cleaning systems some indication of optimum selection of dust-control plant is given.

By R. J. Hamilton,* B.Sc., F.Inst.P.

AIRBORNE dust provides a problem, in one form or another, in almost every industry. It is frequently a health hazard, either by reason of the toxicity of individual particles, or because of the large quantities dispersed into the air in some processes. For example, the inhalation of minute quantities of radioactive dust may cause death within a few days, whereas the breathing of relatively large quantities of coal dust may result in a miner succumbing to pneumoconiosis after a number of years. The abrasive properties and inflammability of various dusts may also result in widespread damage to machinery and plant.

The essential principles of dust control are, firstly, to minimise its production, secondly, to stop, as far as possible, particles formed from becoming airborne and, finally, to provide ventilation systems to remove airborne dust before it is dispersed into the main body of air and becomes, in consequence, a health or industrial hazard.

Before considering methods of dust control in detail, it is useful to examine the composition and properties of the airborne particulate clouds met with in industry. Solid *dust* particles are produced by such processes as grinding, blasting or drilling and, in the case of those produced by breakage of a brittle material, form part of a 'spectrum' of particle size with a distribution peculiar to the material. In typical airborne clouds of such particles, the top size is usually not more than 100 microns, and the smallest may be less than 0.1 micron, although these very finest particles have a tendency to form aggregates and are often difficult to distinguish from the general air pollution background. Fumes and smokes are produced by processes involving heat and are conventionally distinguished by being inorganic and organic in origin respectively. Such particles have a strong tendency to aggregate and their top size is almost always less than 1 micron. Finally some industrial clouds are mists or fogs, formed of droplets produced by condensation of liquids on nuclei or by liquid atomisation.

Falling speed

Neglecting questions of toxicity, the most important parameter of an airborne particle is its falling speed. This defines its behaviour in an airstream and in air-cleaning apparatus, and determines whether or not it is breathed into the lungs.

In the size range 0.1 to 100 microns, airborne particles, in general, obey Stokes' law, and their falling speed is given by the expression:

$$V_s = \frac{2}{9}\frac{r^2 \rho g}{\eta_i}$$

where r is particle radius (cm.), ρ its density and η_i the viscosity of air (poises).

Typical falling speeds in air for spherical particles of unit density are:

for diam. 0.5 micron, 0.001 cm./sec.
5 micron, 0.076 cm./sec.
and 100 micron, 25 cm./sec.

Particles smaller than 0.1 micron behave effectively as gas molecules and their removal from the air under normal conditions is caused by the processes of diffusion and Brownian movement rather than by gravity settlement. Particle velocities, in fact, tend to rise with reduction in size under these conditions, and minimum activity occurs at about 0.25 micron diameter.

It is important to remember that industrial dust particles are frequently of irregular shape, and their falling speeds are lower than those of spheres of the same density and mean projected diameter. The difference between projected diameter and 'Stokes diameter', which is defined as the diameter of the spherical particle of the same density and falling speed, can be very large indeed, particularly for long fibrous particles, such as those produced in processing asbestos.

A parameter related to the free falling speed of a particle is its 'stopping distance'. If a particle is projected into still air with a velocity V, then it will travel a distance d, given approximately by the expression

$$d = \frac{2r^2 \rho v}{9\eta_i}$$

before coming to rest. Similarly, if an

**Mining Research Establishment, National Coal Board, Isleworth, Middlesex.*

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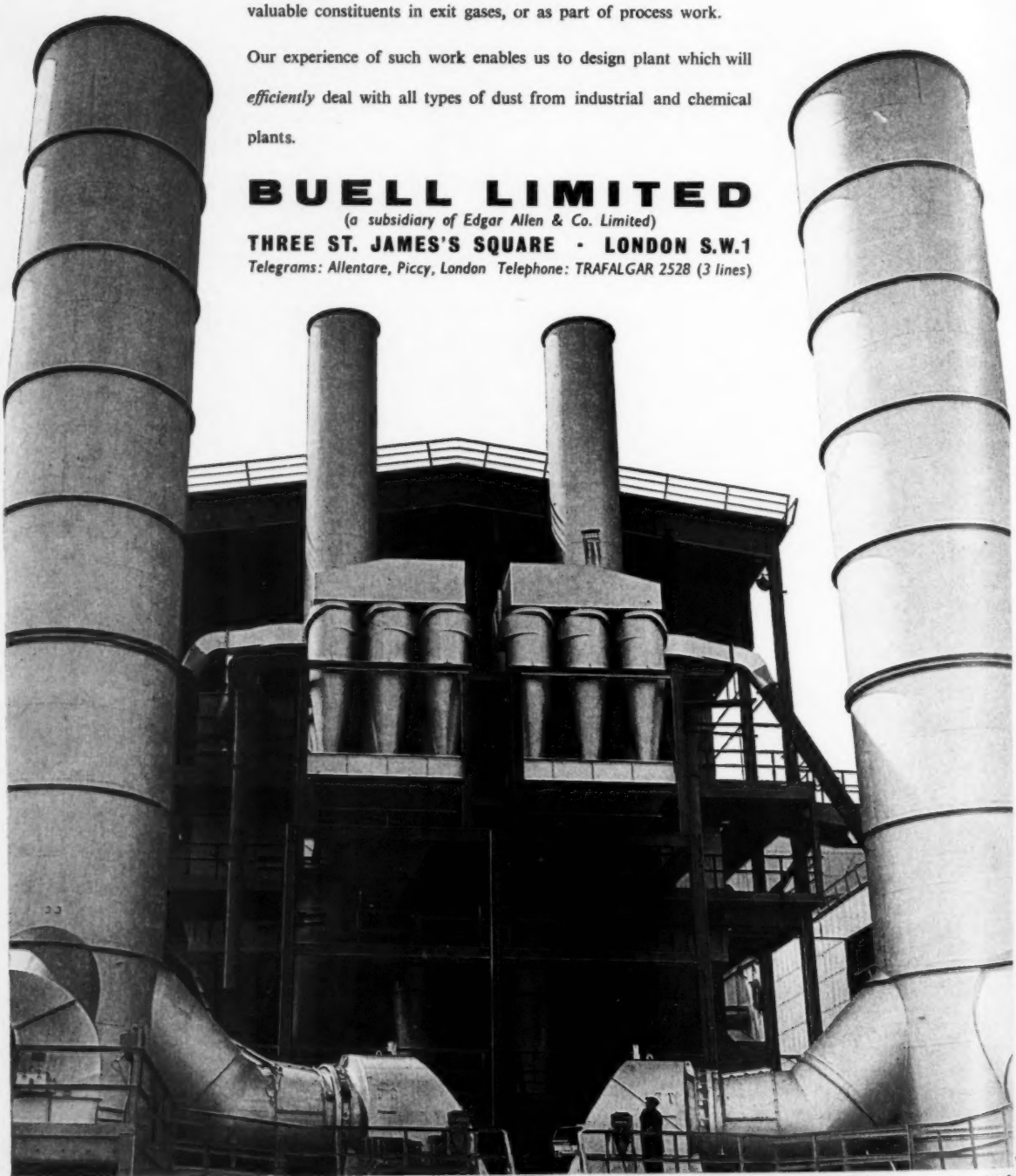

airstream carrying particles is diverted, the particles will continue to move in the original direction, and eventually diverge from the original air flow lines by their stopping distances.

Typical stopping distances for unit density spheres projected initially at a speed of 1,500 cm./sec. (3,000 ft./min.) are:

0.5 micron diam.:		0.03	mm.
5	,, ,,	3	mm.
100	,, ,,	120	cm.

Control of dust formation

Any breakage process results in the formation of some dust, and the only effective method of reducing the amount of this finest debris produced appears to be to alter the overall size distribution by increasing the size of the largest pieces of debris. For example, in rotary drilling, quite substantial reductions in the make of fine debris can be achieved by increasing thrust and, consequently, penetration per revolution (Fig. 1). A limit to the reduction is set in this case by the design of the drill, which does not allow very large pieces of debris to escape intact through the space between drill rod and the walls of the hole.

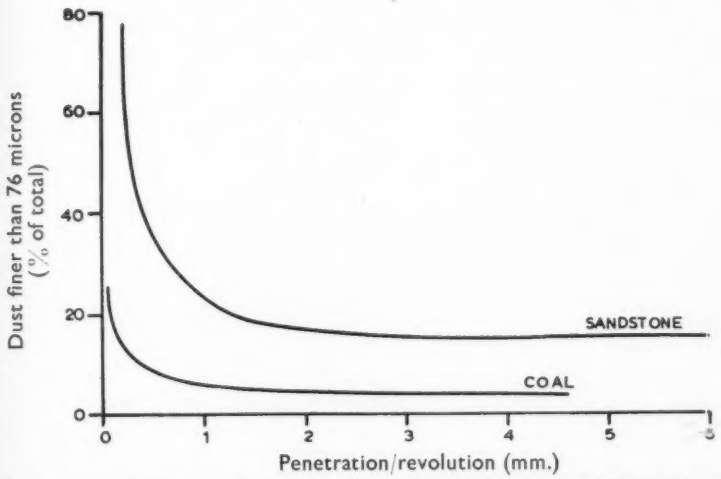

Fig. 1. Rotary drilling: variation of dust production with penetration/revolution.

Whereas there is no evidence that speed of working causes more fine dust to be made, the use of fast-moving cutting tools causes fine particles to be more readily dispersed into the air—this is particularly noticeable when rapid air movement is also produced by tool movement, as in percussive drilling.

Frequently, dust is dispersed into the air during the movement of already broken material; conveyor transfer points, tipplers and loading points being typical sources of dense clouds of particles produced both by redispersion of already present dust and by fresh breakage. There is a tendency for such dust clouds to be much coarser than those produced by 'primary' breakage processes, since most of the finest particles have formed aggregates and, in consequence, there is usually rapid settlement of dust near its point of origin. In many cases substantial reductions in dust dispersion can be obtained by the use of chutes to avoid any free fall of debris and, where some free fall is unavoidable, the enclosure, as far as possible, of the dust source, in order to avoid the excessive air movements which are caused by the falling material.

Dust suppression

The term 'dust suppression' is used to describe the technique of stopping particles from becoming airborne. The most common method of doing this is by application of a liquid, usually water. In coal mining, for example, an established dust suppression procedure, known as water 'infusion', involves the injection of water under pressure into holes drilled in the coal face before normal mining techniques are used to extract the coal. When such a preparatory technique cannot be used, effective reductions in dust dispersion can be obtained by applying water to the cutting edges of tools in such a way that contact is made between dust and liquid at the moment of formation. A technique of flushing the cutting faces of tools appears to give the best results. Some dust suppression occurs if water is applied by such means as a spray directed generally at the cutting zone, but in this case it relies to a large extent on the collision of airborne water droplets and dust particles. Under these conditions there is very little effect on the finest particles (smaller than 5 or 10 microns), but efficiency rises with increase in particle size.

In the handling of already broken material, for example on conveyor belts, it is relatively simple to apply a liquid, normally water, by spraying on to the bed of material, and almost complete avoidance of dust dispersion can be achieved. The most important requirement is that there must be intimate mixing of water with the broken material, and it is sometimes worth while to install a simple mechanical mixing device to do this. Thorough wetting of material at the start of a transport system is more effective in suppressing dust than the use of sprays at individual transfer and loading points. Sometimes it may be advantageous to use wetting agent solutions in place of water in order to improve the spreading of liquid over the material, although, in general, mechanical mixing appears to be more effective. Long-term effectiveness of this type of 'dust proofing' treatment may be obtained by the use of oil, applied either alone or in the form of an aqueous emulsion of 'soluble oil'. Solutions of hygroscopic salts may also be used, although these have often obvious disadvantages. Binding agents applied in solution which, after evaporation of water, leave only a solid bond, do not appear to be effective.

Control of airborne dust

A certain measure of dust control may be achieved by the use of high levels of general ventilaton to dilute airborne dust concentrations to sufficiently low levels. However, even if average conditions are satisfactory, it is impossible to avoid high local concentrations of particles, and present-day practice is aimed at the isolation of individual dust sources. The ultimate development of this technique is found where there is a risk of very toxic particles being dispersed. For example, the machining of radioactive materials must take place entirely by remote control within enclosures from which air is continuously removed.

The design of an exhaust ventilation system for a piece of machinery or other dust-making process is worthy of considerable care. In addition to

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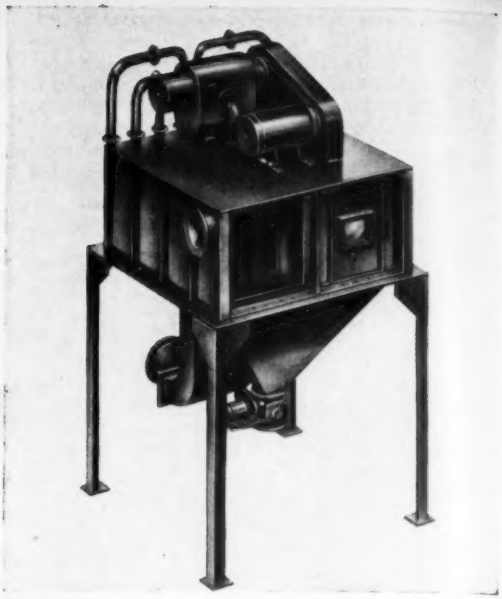

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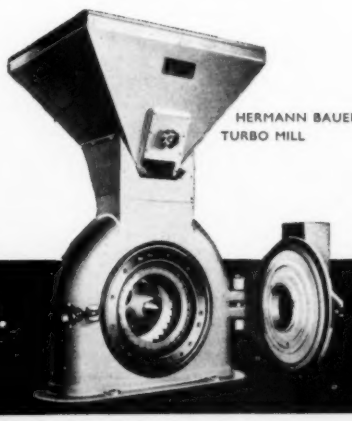

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ensuring that dust particles do not escape into the general body of air, it is desirable that the quantities of air moved should be kept as small as possible, since excessive exhaust ventilation can give rise to general heating and ventilation difficulties, and the cost of ducting, air-cleaning apparatus and air-moving can become very great.

As a preliminary to the provision of an exhaust system, a study should be made of the dust-making process and of any local air movements it induces.

Table 1

Air velocities at dust sources required to provide effective capture of particles

Conditions of generation	*Minimum air velocity at dust source (ft./min.)*	*Typical processes*
Released without noticeable air movement	50	Evaporation of vapours
Released with low air velocity	100—200	Paint spraying in booths, dumping dust into hopper
Active generation	200—500	Stone cutting, rotating mixers, loading conveyors
Released with great force	500—2,000	Grinding, heavy crushing

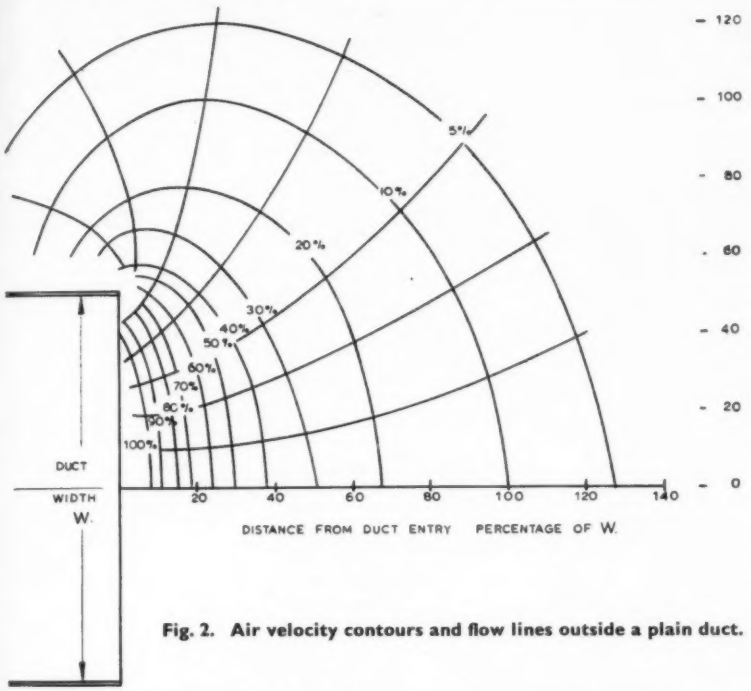

Fig. 2. Air velocity contours and flow lines outside a plain duct.

For example, the free fall of debris causes an appreciable displacement of air, rotating grindstones carry air and dust particles round with them and eject particles tangentially, and there is also considerable vertical movement of air around and above hot bodies, as in hot casting shake-out in foundries. The examination of such air movements, both before and after the installation of an exhaust ventilation system, can often be carried out quite easily by using a small smoke tube. Similarly dust dispersion may be photographed, making use of light scattered by particles too small to be seen directly. It is, of course, necessary to use a darkened room for this work, with a strong light beam illuminating only the dust source; the dust is then best photographed from a direction a few degrees from that of the direct light beam.

The first working requirement for a local exhaust ventilation system is that air should be drawn towards the dust-producing zone at not less than 50 ft./min.: an air flow rate greater than the highest velocity produced by the general ventilation. When the dusty zone is rather large as, for example, an acid bath, it may be necessary to restrict the air entry to the zone in order to obtain this flow rate. Under conditions when air movements are created by the dust-producing process itself, this inward air flow must sometimes be increased, up to perhaps 200 ft./min.

The second essential requirement for an exhaust ventilation system is that the air velocity at the dust source is high enough to ensure capture of a large proportion of the particles formed. In fact, this air speed induced by the exhaust system must be sufficient to control the air movements caused by the dust-forming process. To a certain extent also, the ' stopping distance ' of particles may effect capture efficiency, particularly for the largest sizes.

Smoke and fume particles are normally released gently, air movements are low, particle size is small so that ' stopping distances ' are negligible, and adequate control may be achieved by quite low exhaust velocities in a simple enclosure, as, for example, the laboratory fume cupboard. Restriction of access to achieve the 50-ft./min. ventilation velocity into the enclosure is the only requirement. On the other hand, dust particles produced by relatively violent processes, and often of large size, require high ventilation velocities at source to achieve effective control. These are usually obtained by the use of small exhaust hoods mounted close to the dust source. Table 1 (after Drinker and Hatch) gives an estimate of necessary air velocities for effective capture of particles of various types.

Velocity contours at duct entry

There is a tendency for air to enter an exhaust duct from all directions, with the result that velocity falls off rapidly with distance from entry. Dalla Valle has given the following empirical relationship between velocity and distance along the axis of round or rectangular exhaust openings:

$$V = \frac{Q}{10x^2 + A}$$

where x is distance, Q is the volumetric rate of air flow and A is the area of the opening.

Fig. 2 (after Alden) shows the velocity contours and air flow lines at a plain duct entry and indicates the rapid reduction in velocity. Some gain is obtained by fitting the duct entry with a wide flange, thus reducing the flow of air from the area behind the entry. Fig. 3 shows the velocity

contours round flanged and unflanged entries.

For practical purposes the maximum air velocity at the entry to an exhaust duct is about 3,000 ft./min., set by considerations of duct resistance and fan load. It will be clear, therefore, that for effective removal of dust particles produced with any violence, the duct entry must be placed close to the source of dust, preferably not further away than one duct diameter. It is of obvious advantage also for the direction of exhaust ventilation to coincide, as far as possible, with the direction of initial particle movement. Fig. 4 shows an exhaust hood fitted to a grindstone, providing high air velocities at the dust source. Fig. 5 shows canopies designed to protect workers engaged in the fettling and scurfing of castings. In this latter case particle velocities and induced air movements are not high and effective control is

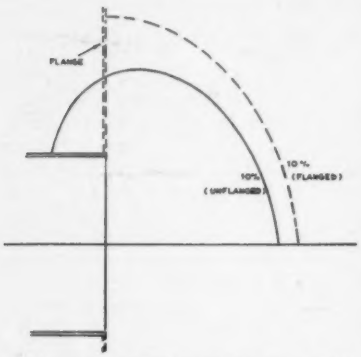

Fig. 3. Air velocity contours outside flanged and unflanged ducts.

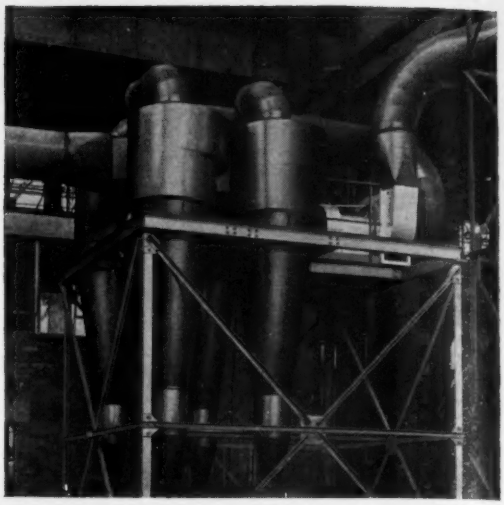

Fig. 10. A multi-cyclone unit of W. C. Holmes Ltd.

Fig. 5. Exhaust hoods for fettling and scuffing of castings made by Dallow Lambert & Co. Ltd.

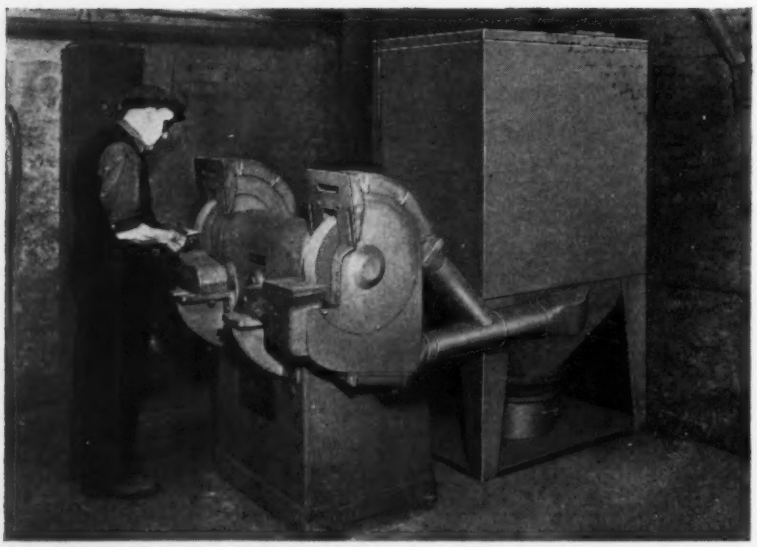

Fig. 4. B.C.I.R.A. exhaust hooding for grindstone by Dallow Lambert & Co. Ltd.

achieved by relatively low exhaust air velocities. Conveyance of dust-laden air from exhaust hood to filtration apparatus requires some thought in design, and care should be taken to avoid excessive pressure drops in the duct system. Minimum air speeds required to convey different dusts range from about 1,200 ft./min. for sawdust to 3,000 ft./min. for various metal and mineral particles. Removal of the dusty air may be to large-capacity air-cleaning plants, serving a number of individual exhaust ventilation systems, such a technique requiring some careful design of the ducting network. Alternatively, individual air-cleaning devices may be used for each exhaust system.

Cleaning of dust-laden air

In general, dust-laden air withdrawn through exhaust ventilation systems should be cleaned before

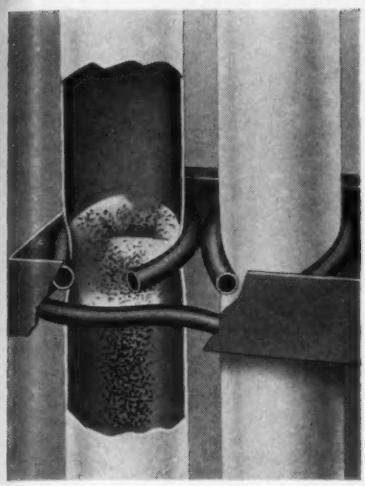

Fig. 7. Reverse jet bag filter by W. C. Holmes Ltd.

being allowed to escape. This is, of course, essential if recirculation of air into working places is permitted, a technique becoming increasingly popular in view of the resultant savings which can be achieved in the cost of space heating. The choice of method must depend on the nature of the dust; high-efficiency filtration is required for fine toxic dusts, whereas simpler and less expensive techniques can be used for coarse, inert dusts. A careful study should be made of the characteristics of the particles which have to be dealt with, before an air-cleaning plant is selected.

Where dust clouds contain fine respirable particles, the only suitable high-efficiency air-cleaning techniques available involve either filtration through cloth or paper, or electrostatic precipitation. The lower limits of particle size collected efficiently by these methods are: for cloth (or ' bag ' filters), about 0.5 micron; for high-efficiency paper filters, about 0.1 micron; and for electrostatic precipitators, about 0.001 micron. A typical free-standing bag filter unit incorporating its own fan is shown in Fig. 6; here the cloth filtration medium is in the form of flat envelopes, and cleaning is carried out by mechanical shaking when the air flow is stopped. Fig. 7 shows a bag filter unit in which cleaning is carried out continuously by small moving jets of compressed air, the so-called ' reverse jet ' principle. A limitation of cloth or paper filtration units is that they can only be used for the collection of solid particles. The electrostatic precipitator, on the other hand, can be used for the collection of both solid and liquid particles and is of great value for the collection of fine mists and fumes. The unit shown in Fig. 8 is of the two-stage type, in which particles are first charged by passage through an ioniser, and are then precipitated on parallel electrodes, charged alternatively positive and negative. A simpler form of electrostatic precipitator consists of a single stage of positive parallel plate electrodes, with negatively charged electrodes, composed of wire grids, supported between them.

Sometimes wet dust collectors, such as venturi scrubbers, which are claimed to have high capture efficiency down to below 1 micron, and those in which impaction of dust takes place on water droplets and on either moving or fixed water-flashed gauze screens, can be used effectively. An example of the latter kind of collector, with a high efficiency down to between 3 and 5 microns, is seen in Fig. 9.

The conventional cyclone is capable of removing particles greater than about 40 microns and is sometimes of value as a pre-filter to reduce the dust loading on a later high-efficiency filter. Nests of small cyclones, of a few inches diameter, such as those shown in Fig. 10, can provide satisfactory collection of particles down to about 10 microns.

Selection of air-cleaning units

Two important points in the selection of an air-cleaning unit are, firstly, to ensure that it has adequate capacity to deal with the expected dust loading without requiring frequent cleaning and, secondly, that it can deal with the required air flow without causing excessive pressure drop or the risk of filter breakdown. The latter requirement is of particular importance with

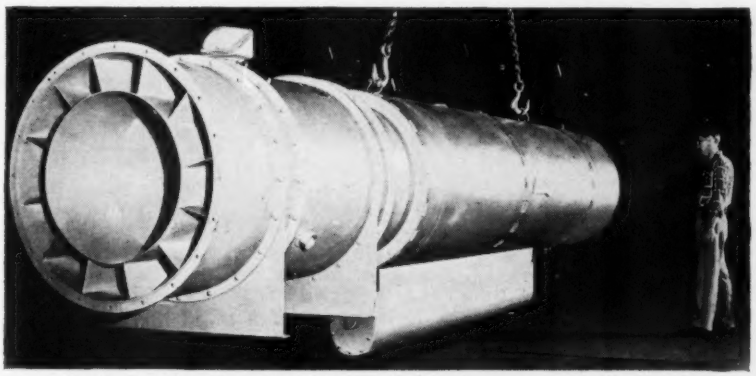

Fig. 9. A ' Microdyne ' inertial wet dust collector by Joy Sullivan Ltd.

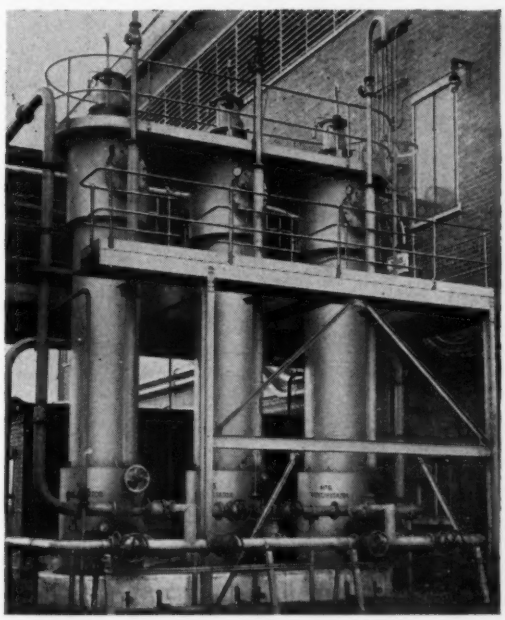

Fig. 8. An electrostatic pricipator by W. C. Holmes Ltd.

fabric filters, and the area of filter surface should be great enough to allow air velocities less than about 10 ft./min. with conventional filters and less than 40 ft./min. with ' reverse jet ' continuously cleaned filters. The efficiency of filtration which takes place in the packed bed of particles varies little with air flow rate, but at too high rates there is a risk of high pressure drop causing the dust deposit to break and blow through the fabric. Frequent checking and good maintenance of all types of filter are, of course, essential.

It may be appropriate here to comment on methods of presenting the dust-collection efficiencies of air-cleaning devices. Frequently overall figures are given of removal efficiency in terms of total mass, when a test dust containing a wide range of particle sizes is used. Such results can be misleading as, although overall efficiency may appear to be high, a considerable proportion of the finest particles may penetrate the filter. It is desirable either to use test dusts composed of a narrow and accurately specified range of particle size or, if a wide range of particle size must be employed, to carry out sampling and assessment of dust concentrations before and after the filter carefully, and to estimate individual efficiencies for narrow size gradings. When the efficiency of collection of respirable dust is required it is recommended that filter performance be measured in terms of the proportion of methylene blue spheres, of size 0.5 to 1 micron, removed from the air, as specified in British Standard 2831: 1957.

This article has been able to do little more than touch on a few aspects of a very wide subject. A list of standard works on the subject of airborne particles and their control is given below for those interested in the problem in any detail.

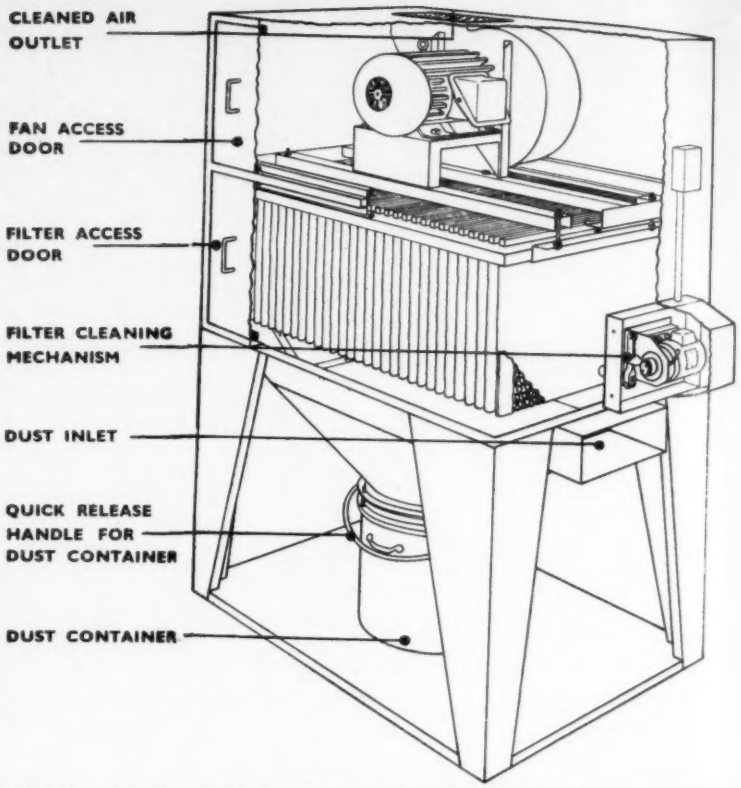

Fig. 6. Free standing bag filter unit—' Unimaster ' by Dallow Lambert & Co. Ltd.

J. L. Alden, ' Design of Industrial Exhaust Systems '. The Industrial Press, New York, 1949.

J. M. Dalla Valle, ' Exhaust Hoods '. The Industrial Press, New York, 1952.

C. N. Davies, ' Dust is Dangerous '. Faber & Faber, London, 1954.

P. Drinker and T. Hatch, ' Industrial Dust '. McGraw-Hill, New York and London, 1954.

H. L. Green and W. R. Lane, ' Particulate Clouds: Dust, Smokes and Mists'. E. & F. N. Spon, London, 1957.

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New chemicals centre in U.S.

Union Carbide recently announced plans for its eighth producing centre for its line of more than 400 organic chemicals for industrial and consumer use. The plant facilities at Brownsville, Texas, will be altered and revised for chemicals production. Construction work will begin immediately and is expected to be completed early in 1961.

Among the chemicals to be made at Brownsville are acetic acid, acetic anhydride, and methyl ethyl ketone. These chemicals will be made in large quantities to fill the demands of the current chemicals market, particularly the rapidly growing surface coating, pharmaceutical, and textile industries.

Industrial Publications

Hydroxyethyl cellulose. A new Union Carbide International Co. booklet describes the properties and uses of *Cellosize* hydroxyethyl cellulose, which is a non-ionic synthetic colloid used in many industries. Data are presented on properties, preparation of solutions, film and coating properties, preparation of water-insoluble films and test methods.

Welding specification lists. A new edition of *Sifbronze* specifications list has replaced the 1957 edition. This booklet provides full technical details of all the different rods and types of flux which comprise the oxy-acetylene welding range together with blowpipes, cutting machines, etc., from Suffolk Iron Foundry Ltd. Particulars given include type of work for which each rod and flux is designed, mechanical and physical properties, and method of use.

Ion-exchange resins. A new catalogue of the Bro-Rad Laboratories includes working data and prices of a large number of ion-exchange materials. The materials covered include anion-exchange resins, cation-exchange resins, mixed-bed resins, amino-acid resins and special resins such as chelating, zwitterion, carboxylic, phosphorous, phosphoric and ion-exchange celluloses.

Cleaning Waste Gases from Open-hearth Steel Processes

By W. Strauss*
M.E., M.Sc., Ph.D.

Cleaning the waste gases from steelmaking in particular the open-hearth furnace process, during oxygen blowing and the L.D. process, is one of the major problems facing the steel industry. In this paper, present processes, including electrostatic precipitation, thermal precipitation, fibre filtration, vertical separation and future developments in furnace gas cleaning are critically reviewed.

IT has been stated that one of the major unsolved problems of the steel industry is the effective control of open-hearth furnace fumes,[1] a problem which in recent years has been aggravated by the increasing use of oxygen in steelmaking. Effective gas-cleaning plant has been developed, but its use requires large capital expenditure and appreciable operating and maintenance costs. These costs are a direct charge on the steel produced, and are only offset slightly by using the captured fume as raw material in a sinter plant and in increased heat economy.

A 200-ton open-hearth furnace produces about 25,000 n.cu.ft./min. of waste gases, *i.e.* about 100,000 cu.ft./min. at 750°C., the approximate temperature of the gases as they enter the waste-heat boiler. Fume concentrations in these cases are usually low; less than 0.4 g./n.cu.m.† during melting, the most time-consuming operation, and only about 0.1 g./n.cu.m. during fettling. Fume concentrations are much higher during refining (boiling) (about 3 to 4 g./n.cu.m.), and during oxygen lancing and lime boiling they average about 6 g./n.cu.m.[2] These data apply generally to both basic and acid melting practice. During most of the cycle of steelmaking operations, the chemical composition of the fume leaving the regenerator is about 50% iron oxide (both Fe_2O_3 and Fe_3O_4), with calcium oxide, silica and the oxides of sulphur constituting much of the remaining material. During oxygen addition to the melt the proportion of iron oxides (mainly Fe_3O_4) increases to over 80% while, during working the melt, boiling and ore addition, it is also above 60%. The sizes of the fume particles vary between 0.01 and 5 microns, but single particles of about 0.1 micron and agglomerates of about 1 micron form the bulk of the fume. On the basis of measurements by Whytlaw-Grey and Paterson[3] it is reasonable to assume that the large agglomerates have a falling speed equivalent to a particle with a density of about one-tenth of the bulk density of the material, but the small particles appear to be solid.

†g./n.cu.m. — *grammes per normal cubic metre. To convert these values to grains per cubic feet, divide by* 2.3.

Removal of fume particles

On the basis of the mechanics of particle motion it has been shown[4] that the mechanisms which can be employed to remove the fine fume particles from the furnace waste gases are:

(1) Impingement and interception of the fume particles by fine fibres, other small particles and/or droplets, these being all of the same order of size as the fume particles.
(2) Diffusion to a surface across a concentration gradient.
(3) Thermal precipitation through a thermal gradient.
(4) Electrostatic precipitation.
(5) Magnetic separation of magnetic particles at temperatures below the Curie point of the material.
(6) Agglomeration of the fume as a precursor to a mechanical separation.

It has been found in practice that these methods are the most successful, and their application will therefore be discussed in greater detail.

Impingement, interception and diffusion

It was suggested by Pring,[5] after some pilot-plant experiments, that bag filters would be commercially feasible on open-hearth furnaces. In pilot-scale experiments the gases were cooled to 140°C. and passed through *Orlon* filter bags, the bag and plant resistance being 1.1 to 1.6 in. water gauge, a low value which could be supplied by 150 ft. of natural-draught chimney. The filtering efficiency was virtually 100%, which is even better than that obtained with electrostatic precipitators.

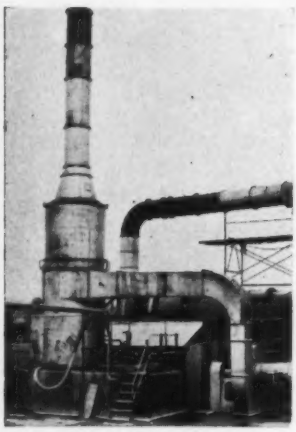
The installation of a large bag filter plant on a 300-ton tilting furnace using oxygen refining to speed the processing has recently been reported in England by Turner.[6] Fifteen compartments with 14 bags in each, 210 bags altogether, are used, giving a filtering area of 5,200 sq.ft. The waste gases are first cooled in a waste-heat boiler, and then further cooled with diluent air to 135°C., so that 730,000 cu.ft./hr., with an initial dust load of 30 g./cu.m., are cleaned to 0.011 g./cu.m. The pressure drop through the bags was 3 in. water gauge. *Terylene* bags, which were tried first, failed amost at once, and *Orlon* bags lasted only for seven weeks. The temperature in the plant has now been raised above the acid dewpoint to 160°C., and much longer filter life has been achieved. Cyclones which were initially installed to clean the coarse material from the fume are to be removed, as their low efficiency (9%) cannot justify their operating cost, as the pressure drop is high. The capital cost of a bag filter plant is lower than that of an electrostatic precipitator, but the space requirements are great, and the maintenance costs, particularly with the replacement of

**Department of Fuel Technology and Chemical Engineering, University of Sheffield.*

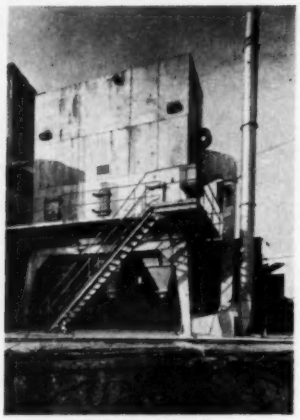
PRODUCTS AND LITERATURE

WET DEDUSTER

This is a triple-stage induced-spray wet deduster designed to give a high extraction efficiency at a low power cost. (Ref. B.38)



WET DEDUSTER



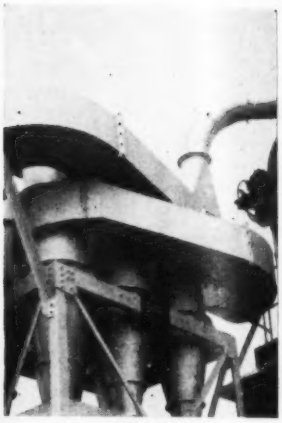
FABRIC FILTER

FABRIC FILTER

This plant is fully automatic and has been specially designed for application in the heavier industries where reliability and trouble-free operation is essential under rigorous conditions. (Ref. B.27)

CYCLONES

These are of particularly robust construction and incorporate a special venting feature which gives the highest extraction efficiency commensurate with economic operation. (Ref. B.34)

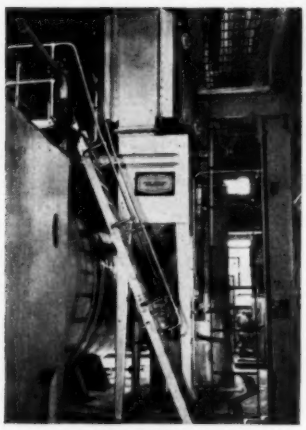


CYCLONES

THE INSUFFLATOR

For the injection of D.C.P. 58 Sulpho-neutralizer into the flue gases from oil-firing processes, such as boiler plant, to prevent acidic-smut emission and to inhibit corrosion. (Ref. B.37)

INSUFFLATOR



TURBOCELL

TURBOCELL

This is an axial-cell medium-efficiency collector designed primarily for the arrestment of dust and grit emission from boiler plant. (Ref. B.32)

LIST OF TECHNICAL LITERATURE

" The Control of Dust in Industry "

" Filtration Fabric Selection " (Ref. B.25)

" Dust Extraction Equipment Specially Designed for the Quarrying Industry" (Ref. B.44)

" The Prevention of Acidic-Smut Emission from Oil-Fired Boilers " (Ref. B.31)

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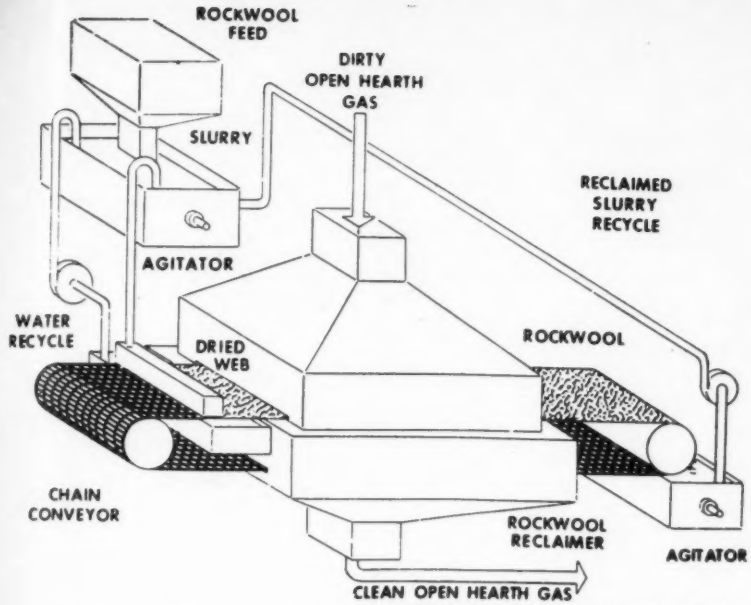
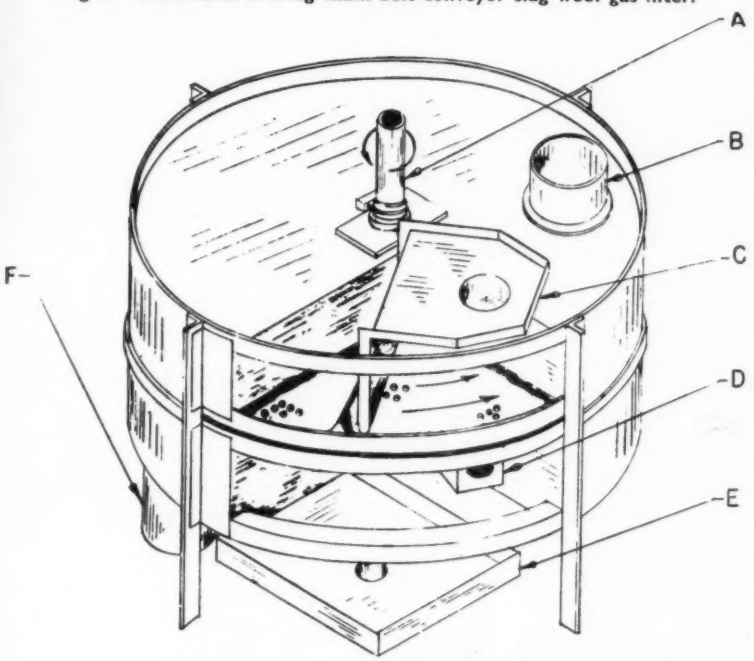


[By courtesy Dr. L. Silverman, Harvard University

Fig. 1. Continuous moving chain belt conveyor slag wool gas filter.



[By courtesy Dr. L. Silverman, Harvard University

Fig. 2. Pilot plant of circular disc design slag wool filter

A = Disc driving shaft
B = Hot dirty gas entry
C = Slag wool slurry charge point
D = Dewatering suction box
E = Draining pan
F = Clean gas exit

bags, would appear to be much higher. The dust load on waste-heat boilers is still very great, and appears to cause considerable operating difficulties.

Very ambitious is the experimental work carried out by workers at the Harvard School of Public Health,[7] where attempts have been made to filter the waste gases hot, before the waste-heat boiler, using slag wool as a filter medium. Laboratory studies were carried out which have shown that a 1-in. layer of slag wool (packing density 5 lb./cu.ft.) will remove over 90% of iron oxide fume from a gas stream at 550°C. at a filtering velocity of 1.67 ft./sec. The resistance to flow was about 2 in. water gauge initially, and increased to 4 in. when the bed was considered exhausted, having collected about 5% of its own weight of fume.

A pilot plant was built, where the slag wool, in the form of a slurry, was fed to a moving-chain belt conveyor (Fig. 1). The hot gases dried the slurry, and formed the filter bed. Owing to mechanical sealing difficulties, the average collection efficiency was only 60%. A modified unit (Fig. 2) was then tried, where the wool was loaded on to a circular conveyor with quadrant sections. The sections were in turn loaded with slurry, dewatered and, after acting as a cleaner, removed. Average resistance of the unit was 4.1 in. water gauge, and the gas velocities ranged from 1 to 1.7 ft./sec. The efficiency of this unit was even lower, averaging about 44%. A screw agglomerator, placed in series with the filter bed, improved the average efficiency to 60%, with a resistance of 6 in. water gauge, and flow rates of 1 ft./sec. through the bed. On some occasions the efficiency was as high as 90%, showing that, with improved mechanical operation and a reduction of leaks, this efficiency could probably be maintained. A slag wool filter with an efficiency of 75% when dealing with fumes from the Linz-Donawitz process has been mentioned by Vacek and Schertler.[8]

Fume collecting efficiencies of beds of different depths of high-temperature insulating brick, crushed and graded between 7 mesh and $\frac{5}{16}$ in., have been investigated by Strauss and Thring.[9] The bed (Fig. 3) was tested at temperatures as high as 600°C., although the filter medium is capable of withstanding much higher temperatures. In some cases the efficiency of a 9-in. filter bed was better than 95%, with a pressure drop of less than 3 in. water gauge and a gas velocity of about 1.7 ft./sec. The average filter efficiency was 80% with an average gas velocity of 1.2 ft./sec., while the pressure drop increased from 2 in. water gauge to 4 in. during four melting cycles of 48-hr. operation, when the bed was used regeneratively.

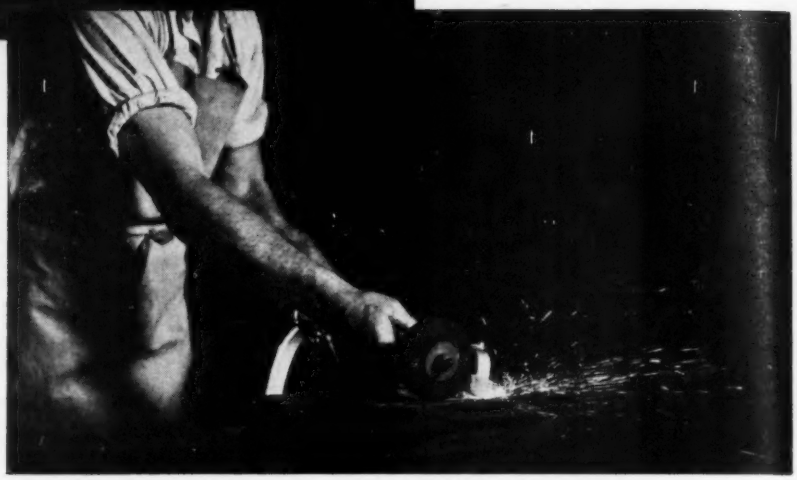
Venturi scrubber

In the venturi scrubber, where high-pressure water sprays are introduced at the throat of a venturi, and this unit is followed by a centrifugal spray

PROBLEM PICTURE – WHERE'S THE DUST GONE?

ANSWER:

EXTRACTED AT SOURCE BY DUSTUCTOR L.V.H.V. SYSTEM



* *The wheel guards have been left off these machines for reasons of clarity*

The Dustuctor low-volume high-velocity system collects the fine dust from a point close to where it is generated by a power tool. The use of low volumes of air at high-velocity makes it possible to convey dust-laden air away from the portable tool through small diameter lightweight flexible hoses. This allows the operator freedom of movement.

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eliminator, the dirty gas is brought into intimate contact with the very finely dispersed water droplets. There is also the possibility of an electrostatic effect due to charging of the water droplets by the atomisation process, but experiments have shown this to be only a minor effect.[10]

The three variables in operating a venturi scrubber are the velocity of the gas in the throat, the liquid-gas ratio, and the liquid distribution in the throat. The high-pressure drop is largely due to the energy required to atomise and accelerate the liquid.

Electrostatic precipitation

Electrostatic precipitation is the method of gas cleaning which has been most widely adopted, particularly in the U.S., where local regulations in many areas demand a clean stack gas. The average efficiency of installed units is about 98% according to published reports both from the Fairless works[11] and the Torrence works[12] of the U.S. Steel Corporation.

Constructional details of one installation have been given by Speer[11] for a plate-type precipitator. The plates are 18 ft. wide, 17½ ft. high and ¼ in. thick, and are spaced at 10-in. intervals, with 18 plates across the precipitator chamber, forming 17 lanes through which the gas must pass. The precipitated dust is removed periodically by an air-vibrator rapping system. The discharge electrodes are $\frac{3}{16}$-sq.in. steel wires, 19 ft. long, suspended at the centres of the gas lanes formed by the collecting electrodes and are negatively charged to 65 kV. There are 10 wires per lane per field, a total of 170 wires per field; and a total of 1,020 wires in the chamber comprising one precipitator. The chambers, which are attached to 330-ton open-hearth furnaces, were designed to handle 75,000 cu.ft./min. at 300°C. with a normal dust load of 1.8 g./cu.m. (based on duct temperatures) and clean this gas with an efficiency of 98%. During oxygen lancing, when the dust load is about 6 g./cu.m., the dust load is reduced to 0.11 g./cu.m. and, even during the checker blowing, when the dust load is twice this, the exit concentration does not exceed 0.23 g./cu.m. Dust collection from the precipitator hoppers is by a suction-line system leading to a primary and secondary cyclone followed by a venturi scrubber, all connected to a common hopper. The dust is thoroughly wetted here to simplify disposal. During lime and ore boiling periods, however, a faint brown plume still exists, although it is hoped to reduce this by improvements to the power regulation and controlled corona electrodes, which double efficiencies under conditions of high load.

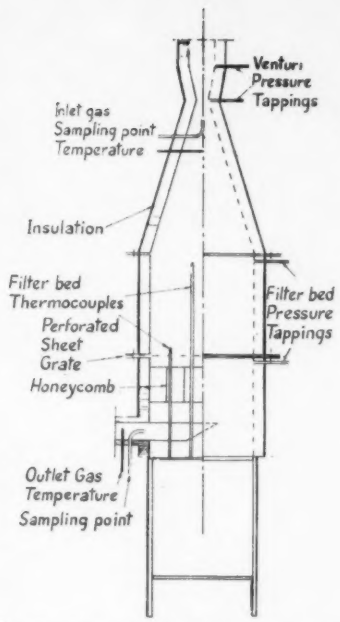

Fig. 3. Pilot plant of reversible filter bed with refractory granules.

From this description the enormous size of an electrostatic precipitator installation can be deduced. Also the gases when they come from the furnaces have first to be cooled in a waste-heat boiler to below 300°C., and sometimes to be preconditioned by the addition of water vapour. Although operating costs are low, the capital costs of the combination of waste-heat boiler and electrostatic precipitator is very high, being of the same order as the rest of the furnace installation. Thus, electrostatic precipitators suffer from several disadvantages: high capital cost, large space requirement and the necessity of using waste-heat boilers under difficult conditions of high dust burden.

Agglomeration studies

The mechanisms which may be applied to increase coagulation and interception between particles of open-hearth furnace fume include sonic energy, thermal diffusion, turbulence and electrostatic charges. One other force can be added: as some of the fume is magnetic, the fume could be exposed to a magnetic field.

Magnetic agglomeration and precipitation was attempted by Vacek and Schertler[8] on fume from the Linz-Donawitz plant, and was 85% efficient. No details of the plant are given. Eden[13] has suggested an electrostatic agglomerator in which charged particles are dropped through a stream of the dirty gases which have been charged with opposite sign.

Sonic agglomeration has been attempted by Vajda,[9] who improved the performance of a type W *Rotoclone* inertial separator when the dust is wetted from 45 to 90%. When sonic agglomeration was tried prior to a simple D *Rotoclone* inertial separator, however, the efficiency of the combination was little better than the D *Rotoclone* by itself. Considering that a sonic agglomerator-cyclone unit with sound insulation costs more than an electrostatic precipitator[14] to install, operating costs are higher and maintenance costs much higher, it is unlikely that this type of gas cleaner will be installed.

Future developments

The only method at present fully developed for cleaning open-hearth furnace gases is electrostatic precipitation. However, as pointed out above, the capital costs are high, and space requirements are such that electrostatic precipitators can only be added on new installations. With recent developments in artificial fibres which are chemically inert to quite high temperatures, the use of bag filters must be considered. Capital costs are lower than for electrostatic precipitators, and long bag life will give low maintenance costs, although space requirements are about the same as for precipitators. Both these methods require the gases to be cooled to less than 300°C. before treatment, imposing a heavy load on waste-heat boilers and reducing the buoyancy of the waste gases when they leave the stack after treatment. This is of great importance, as sulphur dioxide will not have been removed by these treatments and some residual fume will still be in the gases.

A venturi scrubber is very effective, as it will also remove some of the sulphur dioxide, but power costs are high, and the gases are discharged almost at atmospheric pressure. Scrubbing techniques are particularly useful for processes where fuming is very heavy for short periods.

Possible future developments are effective slag wool filters and beds of granulated refractory material. Both units have been shown to be capable of high efficiencies, although not as high as may be obtained with an electrostatic precipitator. Theoretic-

(*Concluded on page* 351)

A Case History

Fume Control and Recovery in Lead Smelting Furnaces

By C. A. Bainbridge*

BECAUSE of economic considerations a large proportion of the high-purity lead made in Britain has to be produced from scrap materials and a number of companies have developed highly efficient methods for the rapid reduction and refining of such materials to high-purity lead for use in the chemical, electrical, atomic, engineering and building industries.

Scrap material in the form of pipe, sheet and blocks is melted down in large pots and refined in what is basically one operation and a large proportion of the total lead produced is made in this way.

Nevertheless a significant contribution to the total comes from old lead acid batteries which cannot be melted down directly because a considerable part of the lead is in the form of lead sulphate ($PbSO_4$) and lead oxides. Lead manufacturers recover the lead from these old battery plates by a process of smelting, whereby the plates are subjected to high temperature in a furnace and the lead sulphate and oxides are reduced to basic lead.

In order to improve the chemistry of the reaction various additions such as soda ash, anthracite, lime, etc., are made during the process and different manufacturers have their own formulae for producing the best results.

Despite careful control of the process inevitably the high temperature in the furnace causes some of the lead to evaporate and when this vaporised lead leaves the furnace it combines with oxygen forming lead oxide and condenses to minute particles of the size order of 0.01 to 0.1 micron. As cooling takes place these particles agglomerate together to form clumps of particles generally 0.5 to 5 microns in size. This loss of lead constitutes an economic disadvantage and manufacturers are naturally concerned to minimise it as far as possible.

Lead oxide in these forms is highly toxic and if inhaled is capable of penetrating into the lower part of the lungs and thence into the blood stream where it affects the blood cells, producing the illness known as lead poisoning or metal fume fever.

Control legislation

Because of its toxic nature lead fume, however produced, has become the subject of control legislation in most countries of the world, and in Great Britain at least three Government bodies enforce regulations designed to eliminate the health hazard of this material.

The Alkali Inspectorate of the Ministry of Housing and Local Government control the problem of air pollution as it affects the community at large. The factory department of the Home Office control the problem of conditions inside the factory and the Ministry of Health have an obvious interest in the health of the workers and have produced various procedures, including compulsory medical examinations, free supplies of milk, methods of treatment, etc.

The requirements laid down by the Alkali Inspectorate to control air pollution specify maximum concentrations and weekly mass emissions in inverse ratio to the volume of gas discharged from a furnace or chimney/min. and shown in Table 1.

Table 1

Volume, cu.ft./min.	*Max. concentration, gr./cu.ft.*	*Max. mass emission, lb./week*
Up to 3,000 ..	0.1	200
3,000 to 10,000 ..	0.05	400
Above 10,000 ..	0.01	1,000

It will be seen from this table that the maximum mass emission allows a higher concentration but limits the number of furnace working hours/week and the maximum allowable concentration, by decreasing with increasing volume, prescribes thereby higher recovery efficiencies for the larger installations.

For example, a 5,000-cu.ft./min. furnace could operate for 138 hr. (20 hr./day for seven days approximately) at 0.05 gr./cu.ft. before exceeding the limit of 400 lb., but could only operate for 69 hr. at 0.1 gr./cu.ft. Again at a nominal exhaust gas concentration of 5 gr./cu.ft. a recovery efficiency of 99% would be satisfactory for a 5,000-cu.ft./min. furnace, but a 10,000-cu.ft./min. furnace would require a recovery plant with an efficiency of 99.8%.

Very few lead furnaces can operate directly to atmosphere without exceeding the requirements and it is now accepted practice to install some form of gas-cleaning plant at the furnace outlet to serve the dual purpose of preventing pollution and recovering the lead driven off in the exhaust gases.

Probably the most popular type of gas-cleaning plant in the lead industry is the fabric filter because of its high efficiency, economy of operation and ease of maintenance, and it is applied in many forms from the old-fashioned, hand-operated, so-called bag house, requiring a relatively large staff, to the modern, fully automatic, multi-compartment plant run by one man part-time.

It is doubtful if any lead manufacturer would consider building the old-type bag house today because of space limitations and labour problems, and even in capital outlay it is not significantly cheaper than the automatic plant, because it must have approximately two to three times the filtering area and generally has to be housed in a special building.

Fully automatic filters with properly designed ancillary equipment are compact, labour-saving and highly efficient, but their application to lead furnace problems requires careful appraisal because of certain factors peculiar to this process. Some idea of the factors affecting a design evaluation

Manager, Dust and Fume Recovery Department, H. Pontifex & Sons Ltd.

can be obtained from the following description of a typical case involving two oil-burning furnaces.

When Lead & Alloys Ltd., makers of high-purity lead and antimonial lead and type metals, erected a new works near Leeds, plans were drawn up for a complete production unit capable of dealing with scrap lead and scrap battery plates with furnaces, melting and refining pots, and mechanised material handling and casting facilities.

Large quantities of scrap battery plates were to be treated and it was decided to install two oil-burning rotary furnaces for this purpose. These two furnaces would require fume control and extraction equipment and a recovery plant to recover the fume for reprocessing and to maintain the dust concentration in the gases discharged to atmosphere below the required limit. Design evaluation began with an assessment of the total volume of gases which would be produced by each furnace and, from proposed fuel consumption figures and air blower capacities, it was calculated that each furnace would produce 900 cu.ft./min. of gas at N.T.P. or 4,850 cu.ft./min. at 1,200°C.

Hood and duct design

The next step was to design the exhaust hoods over the furnaces and here it was decided to install a fixed hood mounted at the exhaust end of the furnace with a charging door operated by a hand winch. The hood was to be in heavy mild-steel construction fully lined with refractory bricks, and so shaped and proportioned that complete control of fume could be maintained when the door was open and material being charged. The hoods were to be set 3 in. clear of the end of the furnace so that atmospheric air could be drawn in by the exhaust gases and cool the gases from 1,200 to 600°C. The resultant gas and air mixture would then discharge vertically upwards through the top of the hood into overhead ducting.

As lead fume is a condensation product and agglomerates on cooling it cannot be conveyed at high velocities otherwise it builds up like a snow drift at bends and changes of section. If it is handled at low velocity, say 1,000 ft./min., it settles out in the horizontal sections and eventually blocks them completely. It is therefore desirable to avoid the use of horizontal ducting wherever possible, but in this particular project because of other requirements it was necessary to use horizontal ducting between the furnaces. The ducting was therefore provided with an adequate number of cleaning doors and fume hoppers with fitted lids to facilitate regular cleaning out.

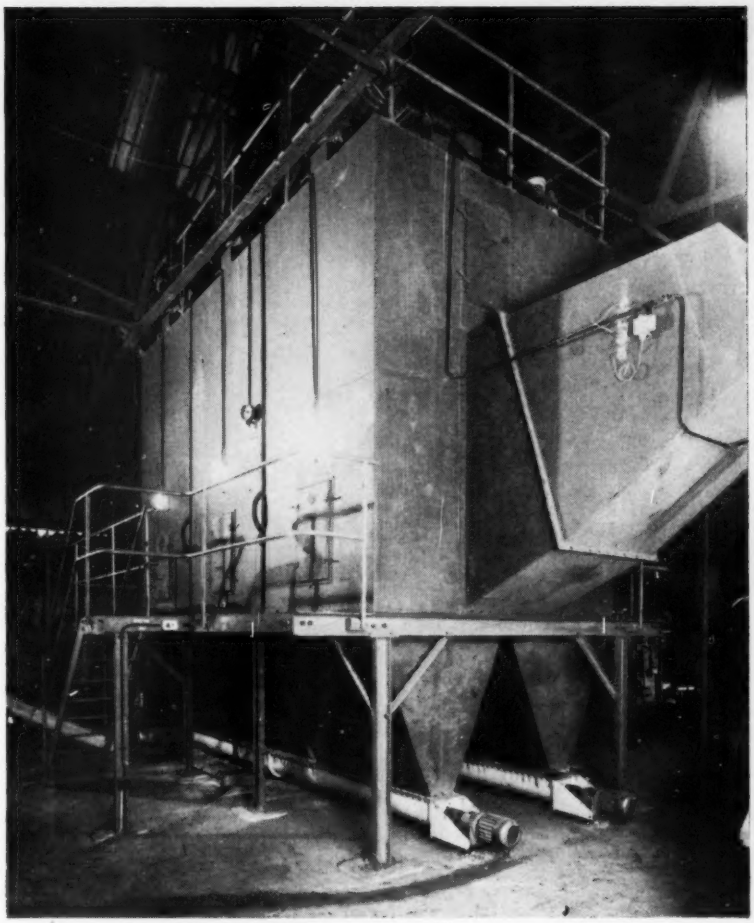

Fig. 1. The compartments arranged in two rows of three.

As the two furnaces would normally work together it was essential to design the ducting between the furnaces and the common main so that an equal draught could be maintained on each without the use of dampers and this was done by means of a precise symmetrical layout to a common overhead main above and to one side of the furnaces. One end of this main connected to an existing steel chimney and the other connected into the gas-cooling plant.

Gas-cooling plant

Before the furnace gases can be filtered they have to be cooled down to a temperature which is safe for the particular filtering fabric chosen and, in this case, the high acid content of the gas, resulting from the sulphur in the fuel and in the battery plates, decided for high-quality grease-state woollen cloth weighing 14 oz./sq.yd. The safe working temperature for this material is 100°C., so it was necessary to cool the gases from 600 to 100°C. before filtering. Because of the low logarithmic mean temperature differences and low overall heat-transfer coefficients below 200°C. it is not economically practical to carry out cooling to 100°C. solely by radiation coolers and, after considering a number of cases of cooling to 250, 200, 150 and 130°C., it was found the most economical arrangement of cooler and filter was given at the 200°C. level. The final design of the cooling section which had to dissipate over 1 million B.Th.U./hr. consisted of a series-parallel arrangement of four 1 ft. 9 in. diam. inverted ' U ' tubes mounted on trough section hoppers connected by a screw conveyor and an isolating valve arrangement for occasions when only one furnace would be in operation.

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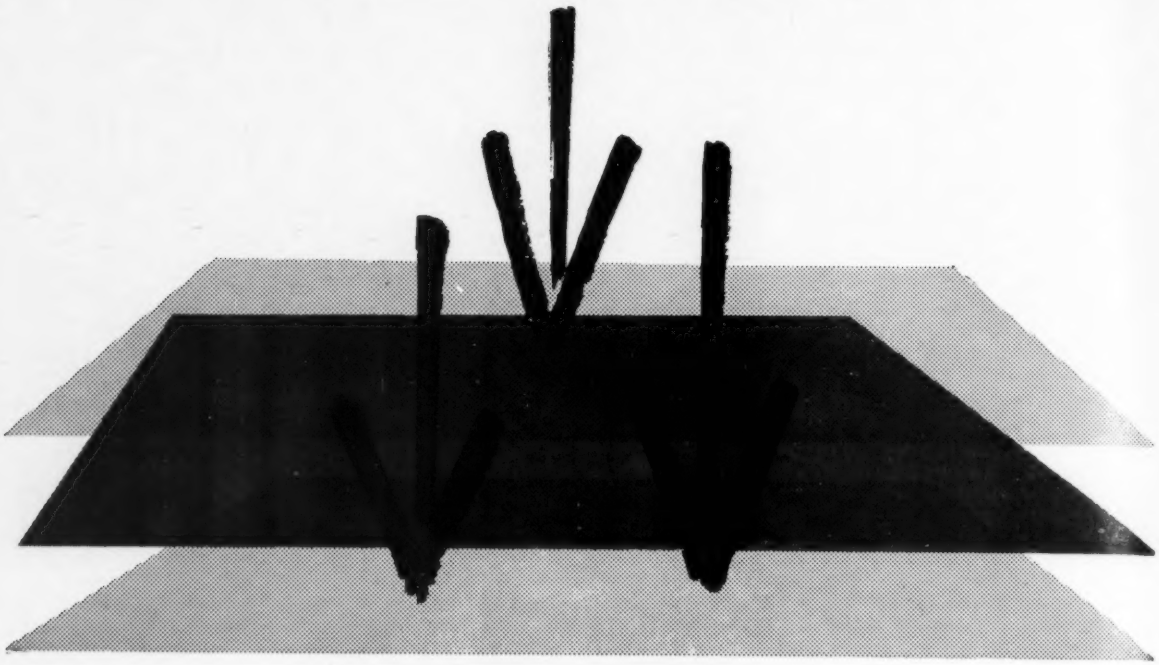

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Fig. 3. The control panel.

Because of the sticky nature of lead fume, cleaning doors were put at the top of each 'U' tube and on each hopper. It is vitally important to remove the fume deposits from the cooling tubes at frequent intervals, as even a ½-in.-thick deposit can completely stop heat flow and a duct having an internal gas temperature of 250°C. can have an external surface temperature only a few degrees above ambient. The fume can best be removed by hammering the tubes with a wooden mallet, causing the deposits to fall off in sheets, the ring of the steel giving a clear indication of the internal condition.

In order to provide precise control of the filter inlet temperature over the whole furnace cycle the final cooling to 100°C. was carried out by the admission of atmospheric air through a thermostatic valve at a point between the cooler outlet and the filter inlet.

Filter plant

Under the maximum operating conditions it was calculated that the total volume of gas entering the filter, including the atmospheric air for secondary cooling, would be 5,000 cu.ft./min. at 100°C.

It was estimated that the maximum dust concentration at the filter inlet would be between 2 and 3 gr./cu.ft. This amounts to approximately 1 ton/24 hr., of which a useful proportion would be lead oxide, the remainder consisting of carbonaceous material from the fuel and battery plates and dust from the metallurgical additions.

These figures are, of course, for peak conditions and for the larger part of the operating time the concentrations would be much less. Nevertheless, the filter cannot be designed for average conditions, otherwise it would be subjected to severe overload during certain periods of the cycle.

The requirements for the filter plant were:

(1) Better than 99.5% recovery efficiency.
(2) Low pressure drop, 3 in. to 3½ in. water gauge.
(3) Flexibility in operation, that is, the plant should be able to handle the full load with two sections out of action.
(4) Sleeve changing and maintenance to be simple and easy.
(5) Adequate protection against corrosion from acid in the gases by preventing cooling and condensation within the filter.

Experience indicated that a maximum filtering rate of 3 ft./min. should not be exceeded if requirements (1) and (2) were to be met. Requirement (3) indicated that at least six compartments would be required and the final choice was a six-compartment *Pontifex* filter with 18 to 8 in. diam. sleeves in each compartment, giving a total filtering area of 2,496 sq.ft. Filtering rates worked out at:

ft./min.
2.03 with all compartments
2.44 with one compartment off
3.06 with two compartments off

Requirement (4) was met by arranging nine sleeves on each side of a central walking space in each compartment and suspending each sleeve independently on a quick-release hook. Requirement (5) was met by installing the filter plant inside the smelter building and insulating all internal surfaces with a 1-in.-thick layer of blue asbestos.

It can be seen from Fig. 1 that the compartments are arranged in two rows of three with the inlet and outlet manifolding disposed internally between the compartments.

Each compartment is fitted with a trough section hopper and the fume is removed by two screw conveyors which deliver into a cross conveyor which in turn delivers to an inclined conveyor which transports the material into the area where it is prepared for reprocessing.

The fan was located at the outlet from the filter so that the system is under negative pressure and toxic fume cannot escape to atmosphere. A further advantage is that the fan handles only cleaned gas. The fan

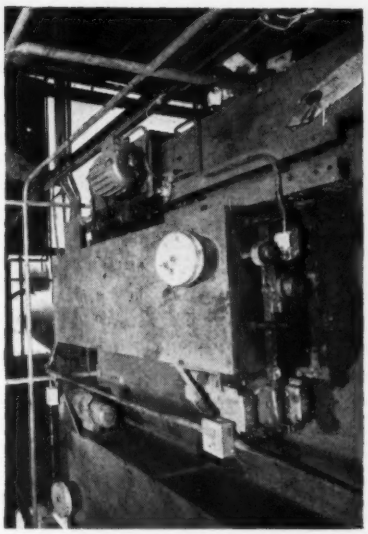

Fig. 2. View of part of the top of the plant.

was rated at 6,000 cu.ft./min. at 100°C. against a resistance of 8 in. water gauge to provide a margin against eventualities, and delivered through the building wall into an existing stack.

Fig. 2 shows a view of part of the top of the plant showing the automatically operated shut-off valves, the reverse air flow valves and the automatic chain-driven shaking gears. Both valves and shaking gears are driven by electric motors controlled from the control panel shown in Fig. 3. In the bottom left-hand corner can be seen the electric timer which controls the shaking cycle, and can be set to give shaking cycles of 10 to 24 min. and shaking times of 5 to 15 sec.

Plant instrumentation consists of 'U' tube manometer for plant pressure drop, dial indicating thermometer with adjustable high-level alarm bell contact for plant inlet temperature and

(*Concluded on page* 351)

MODERN TRENDS IN DUST CONTROL

A RECENT installation has been two portable vacuum - cleaner plants for the cleaning of heat exchangers at the Berkeley nuclear power station. These have been manufactured and developed by the British Vacuum Cleaner & Engineering Co. Ltd., and supplied through John Thompson Industrial Constructions Ltd. Basically the machines are standard large industrial portable vacuum cleaners, using A.B.O. 8 exhausters, but certain modifications have been made in order to facilitate the removal of radioactive dust with the minimum of risk. Pipelines have been constructed in the exchangers and these are attached to special steel-hose connection points with very high-temperature sealing washers, which are left *in situ* during ' steaming '.

To clean the heat exchangers, the operative enters the vessel and, after removal of the caps of the hose connection points, connects the hose to the pipeline and the cleaning tool to the extension arm. This pipeline is connected to the special Model T. 81 machine located outside the exchanger. The dust is collected in a loose polyethylene liner or bag which is inserted into the dust bucket of the filter, and the exhauster is protected by a *Vokes Harwell* boxed canister-type filter, this being guaranteed to separate down to 0.5 micron; dust of this size is considered to be harmless.

Nuclear graphite installation

A dust-extraction installation by Dallow, Lambert & Co. Ltd., serving a machine shop engaged in the manufacture of nuclear graphite blocks for atomic power stations, is shown in Fig. 1. This machine shop consists of two independent but similar production lines. As it is possible to run one line without the other, it was necessary to install two dust-extraction plants, each handling a total air volume of 18,000 cu.ft./min., and it is possible, in an emergency, for the suction main serving one line of machines to be switched over to the opposite plant and *vice versa*. Each plant consists of a 5,000-sq.ft. semi-automatic filter made up of five 1,000-sq.ft. cells. Any one of these cells can be isolated for maintenance purposes while the plant is still in operation, the shaking mechanism of all five cells being energised each time the fan is shut down. Each filter is preceded by two 42-in.-diam., high-efficiency cyclones, the tops of which can be seen protruding above the left-hand filter.

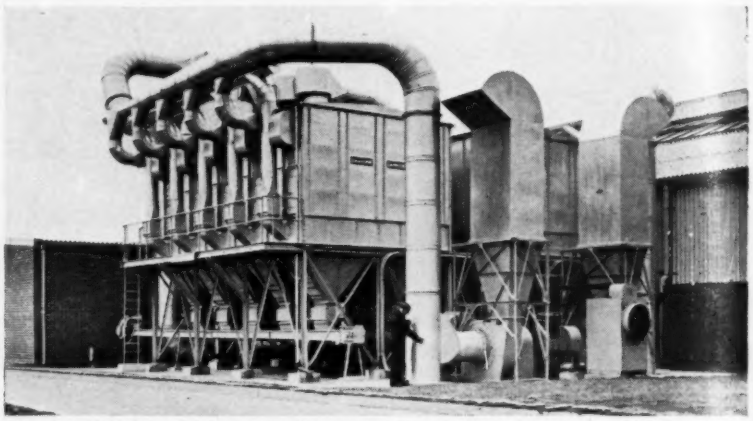

Fig. 1. Dust extraction installation serving a machine shop engaged in the manufacture of nuclear graphite blocks.

These cyclones extract the coarse dust collected prior to the effluent passing into the filter where the final cleansing takes place. The clean air then passes through to the fan, which has an acoustic duct mounted on its discharge side. The small cabinet situated between the two fans is the cooling mechanism unit for the fan motors.

The dust collected by the cyclones and filters feeds into four drag-link conveyors which in turn feed two conveyors in the vertical plane which discharge into a storage hopper situated between the four cyclones. This hopper is equipped with an automatic bagging device, the dust being bagged and stored for shipment in the building which can be seen on the extreme left of the photograph.

'At-source' control

An alarming increase in silicosis and pneumoconiosis among foundry workers occurred during and immediately after the second world war, due to long working hours, bad ventilation due to ' black-out ' restrictions, higher pouring temperatures, the introduction of mechanisation and the wide use of powerful hand-held fettling tools.

The British Government took action to improve working conditions and a special committee was appointed. The report of this committee, the Garrett report, was published in 1947 and, among other recommendations, it stressed the necessity for controlling, if possible ' at source ', the dust produced by portable tools.

Much work has since been done to find a satisfactory solution to this problem which may be briefly summarised as follows:

(*a*) Dust must be extracted at a velocity higher than its initial velocity from its point of origin.

(*b*) The dust-collecting apparatus attached to the tool must be light, very strong, easily adjustable and must not interfere with the use of the tool.

(*c*) The extraction hose must be as small and light and flexible as

possible. The bore must be smooth and the hose must be capable of withstanding rough use.

The operating efficiency of the various cowls and extractor heads has been checked by conventional dust counting instruments, such as the thermal precipitator, but more reliance has been placed on the 'illumination method' which makes use of the Tyndall effect to observe and record by cinematography the movements of the dangerous dust particles within the respirable size range (between 5 and 0.5 micron diam.). This work is done in a room with walls painted matt black, using a 2,000-W. spotlamp to produce the Tyndall beam. The dust-collection equipment of Dustuctor Co. Ltd. is of conventional design, cyclone

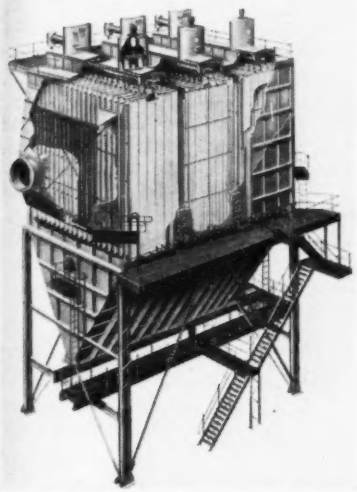

Fig. 2. Precipitator on oxygen process open-hearth furnace gas cleaning.

separators and filters being used. High-speed turbo-exhausters, however, are necessary to obtain the operating depression of 5 in. of mercury. This is, of course, considerably more than the depression required by other ventilating systems which operate usually at between 2 and 6 in. water gauge.

Chimney stack emission

The increase in chimney stack emission as a result of modern steel-making processes has caused much concern. Fine fume particles thrown out can be effectively removed by electro-precipitators, already used extensively in power stations and in cement and chemical works. Although the iron and steel industry has made use of blast-furnace gas precipitators for many years, only recently have precipitators been in operation on steel-making furnaces in this country.

Fig. 2 is a precipitator on oxygen-process, open-hearth furnace gas cleaning, installed by Simon-Carves Ltd. Any particle, however small, liquid or solid, suspended in air or gas, can be collected by an electro-precipitator. Efficiencies greater than 99% are claimed. Some advantages of precipitators are low pressure drop (usually under 0.5 in. water gauge) and low maintenance and replacement costs, while their capacities can range from a few hundred to millions of cubic feet of gas. For instance, a Simon-Carves precipitator installation at Thorpe Marsh power station will deal with 1.5 million cu.ft./min. of flue gas from one boiler unit.

Precipitators are individually designed to suit particular conditions, except for small standard units on certain applications. Depending on the duty of the precipitator, its capacity, efficiency temperature and other factors, operating costs vary accordingly.

Sinter strand dust

Another application for electrostatic precipitators is due to the increased use of sintered ores for blast-furnace operation in the iron and steel works which has led to the installation of many more sinter strands. These sinter strands have created a dust problem in and around the works where they are installed. Lodge-Cottrell Ltd. have developed electrostatic precipitators to deal with this. These precipitators are capable of dealing with the dust from the wind boxes, discharge ends and screens and are said to have given very high efficiencies of 99% and over.

The electrofilters are horizontal-flow type with plate collectors and twisted wire discharge electrodes. The dust concentration at the discharge ends of the sinter plant varies from 6 to 20 gr./cu.ft. at N.T.P., with gas temperatures of 140 to 200°C., and at the screens 1 to 3 gr./cu.ft. with temperatures of 30 to 45°C.

Irrigated cyclones

Irrigated cyclones are offered by Filter Heat Ltd. as dust-collection appliances. They are said to be easy to operate, have few moving parts and do not tend to block up. In the majority of applications the water can be recirculated, but this point is largely dependent on the dust loading of the air stream.

Two methods of cyclone irrigation can be used. The first of these is carried out by feeding water tangentially into the cyclone at four points as near to the top of the parallel body

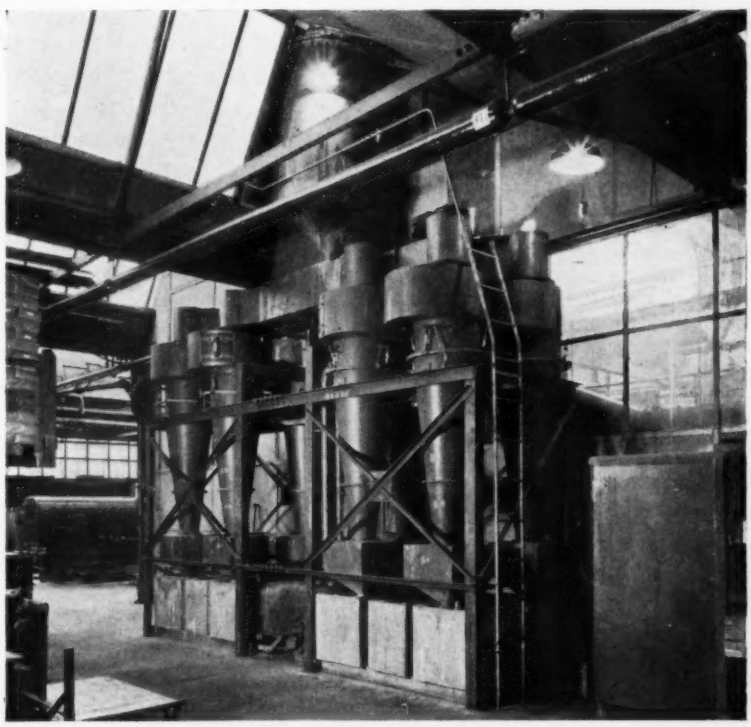

Fig. 3. Irrigated cyclones.

Fig. 4. Wet type collector.

of the unit as is practicable. This has the effect of water-washing the cyclone walls and the water passing downwards through the conical part passes into the settling tank below *via* a water seal. This type of installation is used when dusts which tend to adhere to the cyclone walls are to be collected or where viscous droplets of liquid are entrained in the air stream. It has been applied for dealing with overspray in spray booths.

In the second system it is essential that the cyclone is preceded by a centrifugal fan, preferably mounted so that its discharge is horizontal and at the same level as the inlet to the cyclone. Water is injected into the fan impeller, is broken up by it and mixes intimately with the dust entrained in the air stream before passing into the cyclone itself. The wetted dust, having a greater mass due to the water absorbed by way of adhering to it, is more easily collected.

The cyclone in both systems must be specially designed to prevent emission through their discharges, and must have a water seal incorporated.

Dry-dust filter

A dry-dust filter in which the porosity of the filter media is maintained by means of a high-velocity jet of air in the reverse direction to that of the normal gas flow is called the *B.D.V.-Flo* filter.

Average filter rates of 45 : 1 (cu.ft./min. normal gas : sq. ft. fabric) at average pressure drops between 3 and 6 in. wet gauge have been recorded on such dusts as cement, limestone, sugar, friction dusts, resins and cereals. It can be arranged for operation under suction or pressure and as a self-contained unit independent of any other equipment except electric supply.

No mechanics are contained within the filter housing and no pneumatic or electrical circuits are involved. The source of the reverse air is a rotary blower which extracts the necessary volume of air from the clean-air side of the filter housing. The volume of air passing through the media is, therefore, constant, as is the temperature.

The unit, obtainable from Bramigk & Co. Ltd., is made in a range of standard sizes between 100 to 9,000 cu.ft./min. and larger volume requirements are handled by two or more of the standard sizes installed in banks.

Wet-pad fume scrubber

An extraction unit claimed to have high filtration efficiency (97% on fuming sulphuric acid), low capital cost and low operating costs is offered by Air Control Installations Ltd. The collector is a polyethylene, wet-pad fume scrubber and may be operated as an exhaust or blow-through cleaner with the contaminated gas flowing upward through a perforated plate into the eliminator section This consists of a fluid-bed, polyethylene pad into which water is introduced on a perforated plate and is picked up by air flowing upward through it.

Moving air causes a liquid level to be established in the polyethylene media and subsequently provides a multitude of flooded contact surfaces for effective scrubbing. Excess water is forced down to the sides of the eliminator section and thence downward to a drain pan. Normal drain rate, which is maintained by a sensitive control box, is less than 1 gal. for each 1,000 cu.ft./min./hr.

Wet-type dust collector

A wet-type collector can be considered when a dust has no value or disposal of the material is simpler if it is in the form of a sludge or even a partially dried cake. Another consideration may be that the dust to be collected presents a serious fire or explosion hazard if recovered in a dry collector.

Wet-type collectors, however, are not recommended when a high separating efficiency is essential and in this respect must not be regarded as substitute for textile tube-type collectors. Dust to be handled by a wet-type collector must have some affinity for water which in many cases can be improved by the addition of a suitable ' wetting agent ' to the water. Many dusts cannot be collected with this type of collector under any conditions.

To meet the demand for wet-type collectors when these can be safely used, the Visco Engineering Co. Ltd. has acquired the exclusive selling rights for the *Visco-Handte* patented design in the U.K. and British Commonwealth.

The collector is of the self-induced spray type and comprises a vertical cylindrical casing normally made from mild-steel sheet containing two succes-

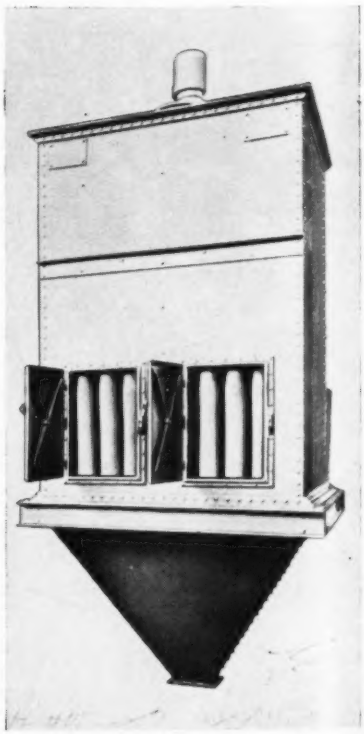

Fig. 5. Self-cleaning unit.

sive cleaning stages, the first being of cyclone type where the air enters through the tangential inlet setting up centrifugal action, whereby the heavier dust is concentrated around the casing before coming into contact with the water level in the lower portion of the unit. At this level, a second cleaning stage by scrubbing occurs: the swirling air, with the finer dust in suspension, is drawn across the surface of the water so as to induce a strong turbulent spray, thus ensuring an intimate mixture between the air and dust and the water, this mixture being drawn up into a venturi throat followed by an expansion chamber, both of which have water-flushed walls to wash the collected dust down into the sump. The cleaned air then passes through an effective moisture-eliminator section before being extracted from the collector through suction ducting leading to the fan inlet, or with the fan mounted directly on the top of the unit casing (see Fig. 4).

Self-cleaning unit

A self-cleaning unit is offered by Keith Blackman Ltd. The basic design employs square fabricated filter chambers having dust-collecting hoppers below and automatic cleaning gear mounted on top.

Filter chambers are cleaned one at a time, the process being automatically controlled from the central timing panel at intervals determined by the operating conditions of the installation. Initially the motor and actuating mechanism of the filter being cleaned close a damper in the main outlet and open one in the purging air inlet. Since the filter chamber is continuously under suction, air is drawn into the dust inlet where it mixes with the normal incoming dust-laden air to be filtered by the adjacent units. Thus, while one filter chamber is undergoing cleaning, the remaining filters handle the full volume of dust-laden air together with air required for purging.

Cleaning Waste Gases (*Concluded from page* 343)

ally a slag wool filter should be able to clean the hot gases as effectively as a bag filter, *i.e.* to better than 99%, but mechanical plant difficulties have not yet been overcome. Beds of granular refractory are quite efficient, particularly if used on a reversing system, and offer the opportunity of heat recovery from the hot granules.

Insufficient data are at present available concerning magnetic filters or electrostatic agglomerators to evaluate their prospects accurately.

The author is greatly indebted to Prof. M. W. Thring for his help and encouragement.

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Fume Control in Lead Smelting (*Concluded from page* 347)

electrical thermostatic control unit for plant inlet temperature control.

Operational experience

When the plant was commissioned it was found that fume control at the hoods was satisfactory and the pressure drop across the plant was initially quite low, about 0.5 in. water gauge, until the fume built up on the filter sleeves, when the plant settled down to a pressure drop of about 3 in. water gauge. The rate of pressure rise between compartment cleaning was about 0.25 to 0.3 in. water gauge and for some days fume escaped through the new sleeves, but ceased as soon as the sleeves settled down. After some further days running the dial indicating thermometer developed a fault and gave low readings and this resulted in damage to a number of filter sleeves which had to be replaced together with the thermometer. Another unusual difficulty which will be mentioned, as it may be of use and interest, was that, although the fan noise level was quite tolerable in the works, for some obscure reason a high-pitched thrumming sound was projected about a mile away from the plant and produced a complaint from the people living in this location.

Investigation showed that the chimney was partly to blame in that a blanked-off branch connection was acting as a resonator box. This was sealed off and, as a further precaution, the base of the chimney was filled with sand. Although diminished, the noise still created a nuisance and as a final step advantage was taken of the reserve fan capacity and the fan speed reduced. This effected a considerable improvement and no serious complaint has since been made. It is thought that the topography of the ground contributed the major reason for the problem, as the plant was located approximately 75 ft. below the road level at the place where the noise was most evident. Under different conditions it is believed the noise would have been projected away from ground level. However, it was apparent that the noise was primarily caused by the particular tip speed of the fan impeller but was amplified by the configuration of the stack and site conditions.

The recovery efficiency is well up to expectations and the plant is now operating to the satisfaction of the user.

Of interest to our readers . . .

A number of articles appearing in our associate journals this month will appeal to readers of CHEMICAL & PROCESS ENGINEERING.

Manufacturing Chemist — Continuous Fermentation in Industry, by G. D. Wilkin.

Food Manufacture—World Food Supplies, World Requirements, by F. Aylward. Infestation and Food Storage, by E. E. Turtle. Factory visit to Leiner's gelatine plant in Treforest.

Dairy Engineering — Automatic Blending of Butter, by J. M. Cansick. Colombia's Contribution to Dairying in South America, by C. W. Hall.

World Crops — Machinery for Grass Conservation, by W. H. Cashmore. Royal Agricultural Show review.

Paint Manufacture—Selection of Resins for Printing Inks, by E. A. Apps. Lanolin in Inks, by E. S. Lower. Paraformaldehyde in Alkyl Resins, by A. W. E. Staddon. Paints at the Milan International Fair by G. Coppa-Zuccari.

Corrosion Technology — Pitting Corrosion, by F. R. A. Dudley. Soil Micro-organisms in Relation to Cathodic Protection, by J. O. Harris. Corrosion Inhibition in Refinery Process Streams, by D. L. Brown, R. L. Hildebrand and P. D. Thomas.

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Structural Problems in Reactor Engineering

By R. K. Livesley,* M.A.

[Courtesy of the G.E.C. Ltd.

Fig. 3. The grillage in position inside the reactor pressure vessel.

While the design of an atomic power station provides many problems for the structural engineer, the design of the reactor itself is of special interest, since it involves problems not often encountered in other branches of structural engineering. This article describes a few of the problems which occur in designing reactors of the gas-cooled graphite-moderated type.

THE atomic power stations under construction in this country use gas-cooled graphite-moderated reactors as their primary source of energy. A reactor of this type consists essentially of a graphite 'core' which is perforated to receive the uranium fuel elements and cooled by an inert gas such as carbon dioxide. The gas subsequently passes through heat exchangers which generate steam in the same way as the boilers of a power station using conventional fuel. To obtain efficient heat conduction from the core it is necessary to circulate the cooling gas under a pressure which may be as much as 250 p.s.i., while the temperature of the gas leaving the reactor may be of the order of 700°F. A typical power reactor of this type may have a graphite core weighing 3,000 tons and a thermal output of 500 MW.

The reactor structure has two main parts—the pressure vessel and the supporting structure. The pressure vessel which encloses the graphite may be cylindrical or spherical in shape, and must be designed to carry the operating pressure of the coolant. In many of the reactors under construction for power stations in this country the pressure vessel is a sphere with a diameter of the order of 70 ft. and a wall thickness of about 3 in. The supporting structure carries the graphite core, transmitting the weight of the latter to the foundations through the wall of the pressure vessel, and it may also have to carry the weight of the pressure vessel itself. A typical structure is shown diagrammatically in Fig. 1.

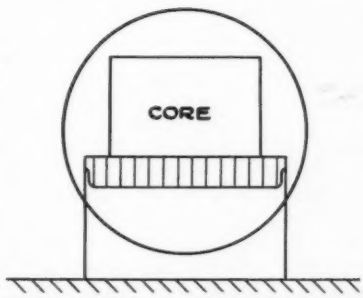


Fig. 1. Section through one of the reactors for the Hunterston nuclear generating station.

General design considerations

The thermal output from a reactor depends on the size of the core and the operating temperature and pressure of the coolant gas. As in conventional power plants, efficiency tends to increase with all these quantities. A limitation on the size of power reactors is imposed, however, by the difficulty of fabricating pressure vessels of suitable thickness—for a given internal pressure and material stress the thickness of a pressure vessel varies in proportion to its radius. The fall in allowable safe stress with increasing temperature also sets a limit on the operating conditions.

The overriding design considera-

*Department of Engineering, Cambridge University.

tions for a reactor structure are, of course, those of safety and reliability. Apart from the disastrous consequences of a rupture of the pressure vessel, even a relatively small mishap may lead to a permanent shut-down of the reactor. It must be remembered that radioactivity makes a pressure vessel and its contents virtually inaccessible for inspection or repair during the life of the reactor. Irradiation also affects the structural properties of the steel from which the reactor is made. Its chief effect is to raise the transition temperature, thus increasing the possibility of brittle fracture. It follows that the designer must avoid stress concentrations which in a normal structure would be ironed out by local plastic deformation.

Apart from safety considerations, there is another reason for the adoption of low working stresses in the reactor structure. This is the need to keep the deflections due to stresses as small as possible. The graphite core, for instance, is not a solid block of material, but is usually formed from stacks of graphite bricks which have little strength themselves. Excessive deflections of the structure supporting these stacks may prevent the charging and control equipment of the reactor from operating properly. In the same way, excessive expansion of the pressure vessel may cause serious stresses in the various pipes and ducts connected to it.

Another problem which the designer has to face is the need to allow for stresses and deflections due to temperature changes. The thermal coefficient of expansion of graphite is different from that of steel, and this factor must be considered in designing the structure which supports the graphite. Temperature gradients in the structure supporting the pressure vessel may also give rise to severe stresses unless precautions are taken.

Structure supporting the core

We now turn from general considerations to discuss two of the problems which occurred during the design of an actual reactor. This reactor was designed by the G.E.C. and Simon-Carves Atomic Energy Group for the nuclear power station at Hunterston in Ayrshire,[1] which is being built for the South of Scotland Electricity Board.

The design of the structure for supporting the graphite was complicated by the fact that the reactor uses bottom-charging for the fuel elements. This method of charging requires a structure which does not restrict access to the bottom of the core, and it was felt that the best means of achieving this was by placing the core on horizontal perforated steel plates, supported on a grillage of deep plate girders. These girders are supported at their ends by a circular ring, which rests on top of a circular cylinder. This cylinder carries the weight of the core down to the foundations, and in its lower part carries the weight of the pressure vessel as well. The arrangement is shown diagrammatically in Figs. 1 and 2, while Fig. 3 shows the grillage during the erection of the reactor. It would, of course, be structurally desirable to support the grillage on a cylinder of radius smaller than that of the core, with part of the grillage cantilevered out, but in the present case this is prevented by the requirements of the charging system mentioned earlier. The spacing of the grillage beams is dictated to some extent by the arrangement of the holes in the graphite which carry the fuel elements.

An initial rough stress analysis for a grillage of this type may be carried out either by treating the grillage as a flat plate, or by considering the weight of the graphite as a series of concentrated loads at the mesh points and assuming that at each mesh point the load divides equally between the two beams. For the design shown in Fig. 2 it was later found that the latter assumption over-estimated the stress and deflection at the centre of the grillage by about 20%, as compared with more exact analysis.

There are now several general computer programmes[2] for the analysis of grillage systems of this type. However,

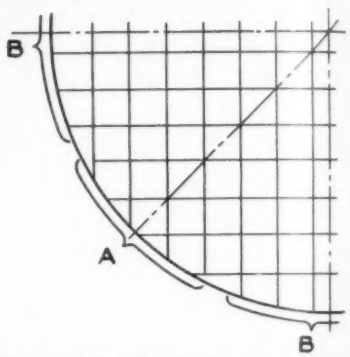


Fig. 2. Plan view of the grillage layout in the Hunterston reactors.

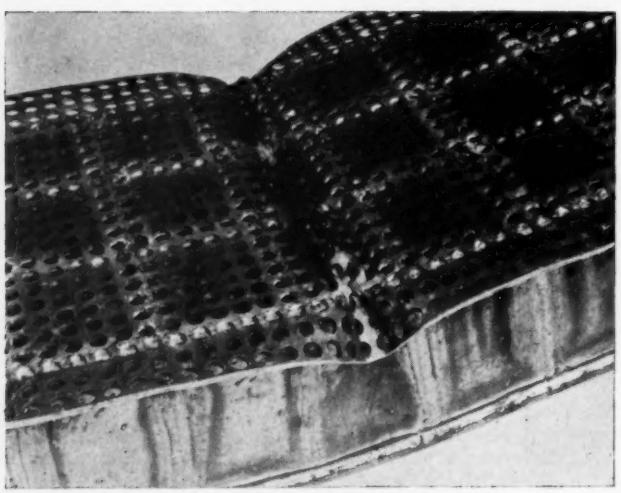


Fig. 5. Failure mode of model of grillage.

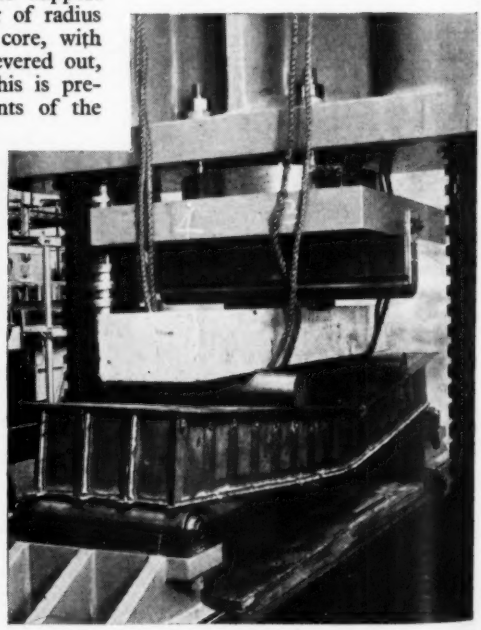


Fig. 4. Model of section of grillage under test.

these were not available at the time when this particular design was carried out, and the analysis was done partly by hand.[3] The method used is quite straightforward, and involves taking the fractions of the applied loads at the mesh-points carried by the x-direction beams as the unknowns. Since the loading is symmetric only one octant of the complete grillage need be considered. The forces acting on all the beams can be written down in terms of the applied loading and these unknowns, and the condition of compatibility of displacements of the x- and y-direction beams at the mesh points then gives a set of equations from which the unknown forces can be calculated. Once the unknown forces have been found it is simple to determine the deflections and stresses in the grillage. This method does not allow for the torsional stiffness of the beams, but shear deflections may be included.

In this particular design there were 19 unknown reactions and hence 19 compatibility equations to be solved. The main part of the work lay in the calculation by hand of the coefficients in the equations—the subsequent solution was done in a few seconds on an electronic computer. One of the interesting and unforeseen results of this analysis was a variation in the vertical forces applied by the supporting ring to the ends of the beams. It was found that, although the load distribution on the grillage had radial symmetry, the vertical reactions at the boundary showed a strong tendency to concentrate in the regions marked *A* in Fig. 2, being considerably less in the regions marked *B*. The variation in average load per unit length of boundary was of the order of $\pm 50\%$. Although not serious, this variation in boundary loading was felt to be undesirable, and later a grillage with beams of varying depth was designed which gave a more uniform distribution of boundary loading.[2] For fabrication reasons, however, the grillage of constant depth was adopted for the Hunterston reactors.

At one stage in the design of the grillage the perforated plates carrying the graphite were merely intended to rest on top of the grillage beams. Analytical studies showed, however, that the beams, being very deep and narrow, would have a tendency to buckle along their upper edges, particularly near the centre of the grillage. Accordingly it was decided to make the perforated plates integral with the grillage, so that the plates acted as the compression flanges of the beams.

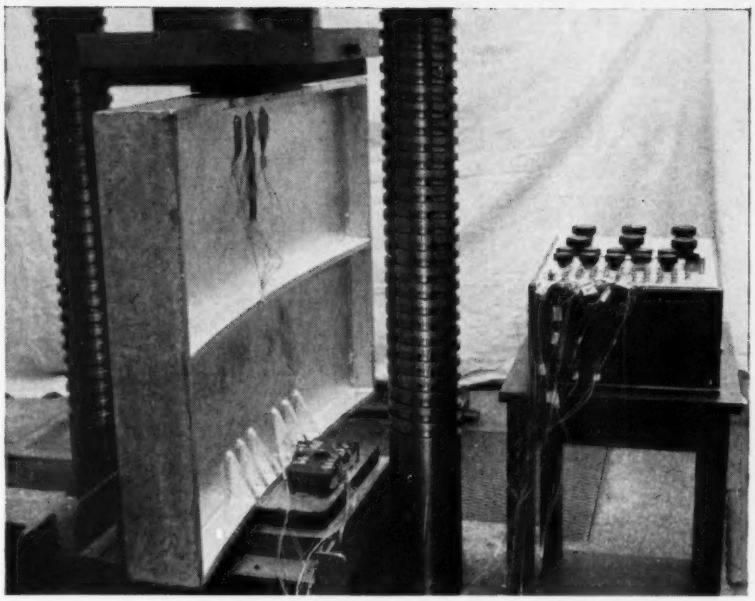


Fig. 6. Section of supporting cylinder under test.

This at once raised the question of the strength and stiffness of a perforated plate. It appeared that no-one had considered even the plane-stress behaviour of a plate with uniform perforations, previous analytical studies being limited to a consideration of either single holes or a single row of holes.

The difficulties of a general analytical study of this problem seemed so severe that it was decided to make a model of a portion of the grillage and test it to destruction. The model, made to a scale of $\frac{1}{16}$ full size, is shown in Fig. 4. The perforations in this case correspond to removal of 48% of the material of the top plate. The test showed that both the strength and stiffness of the model grillage agreed closely with what one would expect from a grillage which had a top plate consisting of a *uniform* sheet containing the same *volume* of material. A close-up view of the point of failure is shown in Fig. 5. Although the grillage actually failed by buckling, it succeeded in carrying 88% of the calculated fully plastic moment of a similar grillage with 'equivalent' uniform top plate, and easily carried its designed loading.

It has already been mentioned that there was considerable variation in the computed values of the supporting reactions for the grillage beams. The largest reactions were well over 100 tons, and doubt was thrown on the ability of the cylinder supporting the grillage to carry such large concentrated forces. It was felt that local buckling of the cylinder under the loads was a possibility which required investigation.

As in the case of the grillage itself it seemed that a test on a scale model would provide more reliable evidence of the safety or otherwise of the cylinder than a purely theoretical analysis. Accordingly, a half-scale model of a section of the cylinder was constructed.

This section was made of sufficient length for the behaviour of the region under the load to be effectively the same as for a complete ring. Fig. 6 shows the model under test in the 500-ton testing machine in the Cambridge University Engineering Department.

Initially tests were made at loads corresponding to the working loads of the full-scale structure, strain gauges being used to determine the stresses in the material of the cylinder under the loading platten, as shown in Fig. 6. It was found that there was no tendency towards buckling under working loads. Afterwards the model was tested to failure, and it was found that, although the plate finally failed by buckling, the deformation was confined to the region in the immediate vicinity of the load. In fact, the buckling did not become noticeable until considerable direct plastic yielding under the load had occurred.

It was realised that, due to the deformation of the grillage itself, the beam ends would be slightly inclined

to the horizontal. Accordingly, further tests were carried out with the loading platten at a slight angle, thus producing an offset load on the cylinder. However, this change had little effect on the ultimate carrying capacity. Finally tests were carried out with a pair of loads, but once again the cylinder proved to have an ample factor of safety.

Stresses in a pressure vessel

The analysis of a complete uniform sphere under internal pressure is very simple. Difficulties arise, however, immediately one attaches a supporting cylinder and coolant pipes, and a great deal of effort has gone into investigating the stress concentrations which may occur at the points of attachment. A junction of particular interest in reactor design is that between the pressure vessel and the supporting cylinder. This junction is already heavily loaded by the weight of the core, and it may be further stressed due to temperature gradients in the lower section of the cylinder. In some reactors a cruciform forging is used to form the actual junction, as the intersection is usually at an oblique angle and may therefore be difficult to fabricate.

The ratio of diameter to thickness in reactor pressure vessels allows them to be considered as 'thin shells'. The mathematical theory of thin shells is well known, and the analysis of a sphere/cylinder junction under temperature stress and dead-weight loading is not too difficult when the loading and hence the deformation have radial symmetry about the vertical axis of the reactor. A more interesting problem arises in considering the behaviour of a reactor under horizontal loading, such as might occur (due to the inertia of the graphite core and the reactor itself) during an earthquake. As an example we shall describe the analysis of the reactor shown diagrammatically in Fig. 7 under such loading. Fuller details of this work have been given elsewhere.[4]

This reactor differs from those designed for Hunterston in having an upper cylindrical support which is attached to the biological shield. This cylinder is designed to prevent excessive deflections of the pressure vessel under horizontal loading, the top of the cylinder being attached to a diaphragm which allows vertical but not horizontal movements.

The deflections of a thin cylinder are governed by an eighth-order partial differential equation. If the solution is expressed as a Fourier

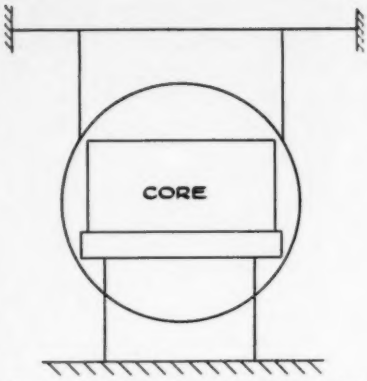


Fig. 7. Section through reactor with upper cylindrical support.

series taken around the circumference, then the first term corresponds to axially symmetric loading and the second to the transverse loading which we wish to consider here. The higher harmonics correspond to load systems which are self-equilibrating. The partial differential equation is thus reduced in our problem to a linear eighth-order differential equation, whose solution is straightforward, though somewhat tedious.

The general solution of this equation has eight arbitrary constants, which must be found by applying suitable boundary conditions. The eight independent solutions fall into two groups. The first group, involving four arbitrary constants, are solutions which give rise to membrane stresses only and, of the four constants, two may be determined by considerations of overall equilibrium while the other two correspond to arbitrary rigid-body displacements. The other four solutions involve bending moments, and the values of the arbitrary constants depend on the edge-bending moments and radial shear forces applied round the circumference of the cylinder at its ends. These solutions are only of importance near the ends of the cylinder, since they are of a highly damped oscillatory nature. Two solutions are predominantly associated with one end of the cylinder and two with the other.

The same type of analysis can be carried out for a section of a sphere lying between two latitudes. Once again there are four independent solutions associated with membrane stresses and four with edge-bending effects. In the case of a sphere closed at the top or bottom some of these solutions can be eliminated, since they would give rise to stress singularities at the poles.

In the system shown in Fig. 7 there are six components—three cylinders and three spherical sections. (The core and its supporting grillage were assumed to be rigid compared with the rest of the structure.) The analysis was carried out by computing boundary values of the general solutions (involving the appropriate arbitrary constants) for the various elements, and then applying conditions of equilibrium and displacement compatibility at the junctions. It would appear that there were altogether 48 arbitrary constants involved, but this number was in fact reduced by applying conditions of overall equilibrium to the individual elements before setting up the final equations. The total number of unknowns after this had been done was 35, this number being made up as follows:

	Arbitrary constants
Top cylinder	6
Inner cylinder	6
Lower cylinder	6
Top cap of sphere	4
Middle section of sphere	8
Bottom cap of sphere	4
Total horizonal shear force applied by top diaphragm	1

These 35 unknowns were found by applying the following equilibrium and displacement conditions:

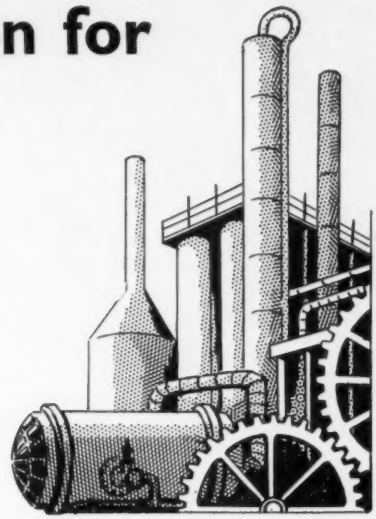
	Equations
Compatibility at lower sphere/cylinder junction	12
Equilibrium at lower sphere/cylinder junction	2
Compatibility at cylinder/grillage junction	2
Zero displacements at base	4
Compatibility at upper sphere/cylinder junction	8
Equilibrium at upper sphere/cylinder junction	4
Conditions at top of upper cylinder	3

As before, the solution of these equations took only a few seconds on a computer. What took the time was the hand computations required to find the coefficients of the arbitrary constants in the equations. These computations took about 40 man-days to complete, and the calculations were in fact duplicated by two different people in order to provide as complete a safeguard against errors as possible. After the equations had been solved the values of the constants were substituted in the various expressions to obtain numerical values for the stresses and deflections.

Apart from the actual solution of the equations all this work was done by hand on desk calculating machines.

(*Concluded on page* 373)

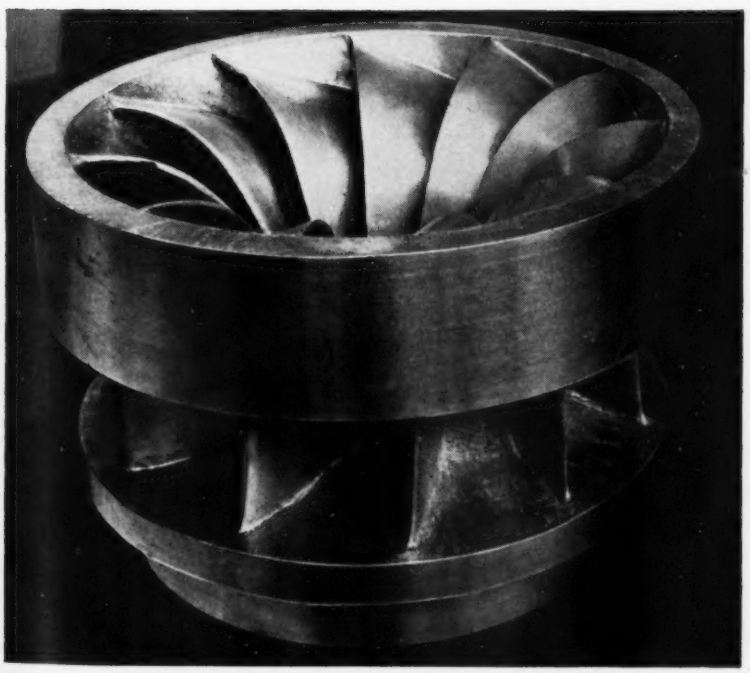
Materials of Construction for Chemical Plant



STAINLESS STEELS

By E. Ineson,* B.Sc., F.I.M.

The fourth article in our series 'Materials of Construction for Chemical Plant' is on stainless steels—previous articles in this series have included PVC, lead and nickel. Stainless steel is rapidly achieving pre-eminence as a favoured material of construction due, no doubt, to the fact that for many applications in chemical plant stainless steel is the only material that can fulfil the stringent requirements as well as ensuring minimum maintenance costs. This article describes the constitution of stainless steels and their physical, mechanical and corrosion properties and, finally, their use in chemical plant is surveyed.



Stainless-steel impeller casting made by A.P.V. Ltd.

THE early history of the discovery and exploitation of the stainless nature of steels containing more than about 12% chromium has been well chronicled by various authorities.[1, 2, 3] Following the initial discovery in about 1912, much extensive development was required before any major use could be made of this type of material in the chemical industry. Appreciable use of stainless steels for chemical plant began in about 1923 when 15 to 16% chromium, 0.1% carbon steel was used in nitric acid plants, but this steel was found to have certain disadvantages in the way of susceptibility to grain growth as a result of operations such as welding and loss of ductility if heated at some intermediate temperatures. The first important milestone appears to have been the construction of a nitric acid plant in 18% chromium, 8% nickel, 0.15% carbon austenitic stainless steel at Billingham. At that time the welding qualities of austenitic steels had not been developed and this first major plant was largely a riveted construction. In the intervening 34 years up to the present time tremendous advances have been made in the development of compositions, methods of manufacture, techniques of working and fields of utilisation, so that even the most complex requirements of modern chemical plant can be met by one or other of the available range of steels. It is probably true to say that the development of the austenitic types of stainless steel has had a greater influence

**Metallurgy Division, British Iron and Steel Research Association, Sheffield.*

on chemical plant construction than any other single development.

The increasing use of stainless steels may be judged from steel production figures for recent years which show that in 1950 the total production of corrosion and heat-resisting steel was about 98,000 tons, whereas in 1959 it was about 192,000 tons. In fact, although since the war total steel production has not quite doubled, in the same period stainless-steel production has trebled and the indications are that this trend will continue. It is perhaps significant that, although there have been continual improvements in types and qualities of stainless steels, their cost has remained much more steady than more ordinary steels. Since 1939 the price of stainless-steel sheet has risen by a factor of only 2.25, whereas ordinary carbon steels have risen in price by a factor of 4.3.

Constitution

Although chromium and nickel are present in comparatively large amounts in stainless steels, the principle element is still iron. It is now well known that iron can exist in two allotropic forms, one of which has a body-centred cubic lattice, existing at high and low temperatures and known as ferrite. At intermediate temperatures iron exists as a face-centred cubic lattice known as austenite. The effect of adding chromium to iron is to suppress the austenite phase, and an iron-chromium alloy containing more than about 13% chromium is entirely ferritic, as shown in Fig. 1.[4] The presence of chromium also confers upon the iron the ability to resist attack by the atmosphere and by many chemical reagents. This property is attributed to the formation of a thin but very tenacious film of oxide at the surface of the alloy, which is continuous for all alloys containing more than about 12% chromium. It resists attack by most oxidising agents and, furthermore, if damaged, can readily heal in oxidising surroundings. The passivity achieved by the stainless steel in this way gives it a solution potential between those of copper and silver, but it must always be remembered that, if for any reason the surface film is damaged or not allowed to heal, the solution potential reverts to that of the base iron. This then is the basis of the stainless irons or ferritic stainless steels as they are frequently called. Ferritic stainless steels generally contain less than 0.1% carbon and are hardenable by heat treatment to only a slight and limited extent. When carbon is added to iron-chromium alloys containing between 12 and 20% chromium they become steels, which are hardenable by heat treatment whilst still retaining the stainless properties conferred by the chromium. Hardening of a steel depends on heating it into the intermediate austenite range, followed by quenching rapidly to avoid recrystallisation to the ferrite state. The resultant distorted crystal lattice produces a fine needle-like microstructure known as martensite which has a great hardness. Hence the hardenable stainless steels are frequently referred to as the martensitic stainless steels. The extent of the austenite field in iron - chromium - carbon alloys is shown in Fig. 2.[5] It will be seen that there is a well-defined austenite field at 12% chromium, but this diminishes with increasing chromium content so that it has virtually disappeared at about 18% chromium. Beyond this chromium content, mixed structures containing austenite still exist for carbon contents greater than 0.2% and, by suitable choice of carbon content, hardenable alloys may be obtained up to about 26% chromium. Unfortunately, in the higher chromium alloys the carbon combines with a lot of the chromium and prevents it from being so effective in corrosion resistance. At 30% chromium the iron-chromium-carbon alloys are no longer hardenable by heat treatment, being essentially ferritic at all temperatures up to the liquidus.

Whereas chromium has the effect of stabilising ferrite in iron-chromium alloys, nickel has the opposite effect of stabilising austenite. Fig. 3[6] shows the equilibrium phases for various nickel and chromium contents. However, perhaps the most important function of both chromium and nickel is in their combined ability to slow down the allotropic transformation so

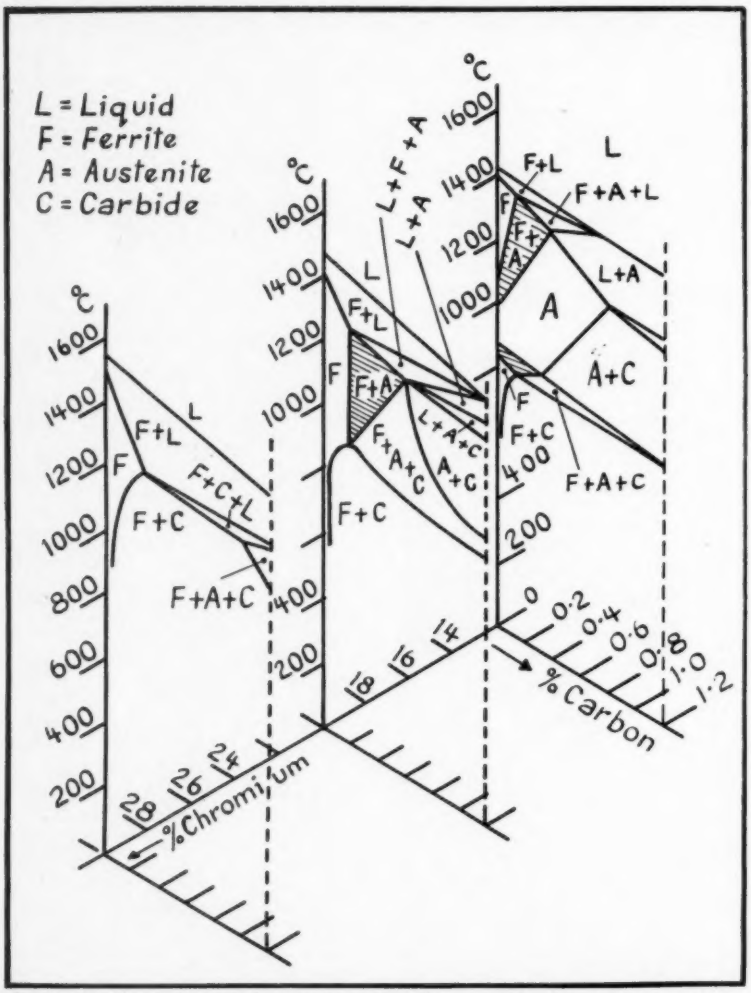


Fig. 2. Sections through iron-carbon-chromium constitutional diagram (after Tofante, Küttner and Büttinghaus[5]).

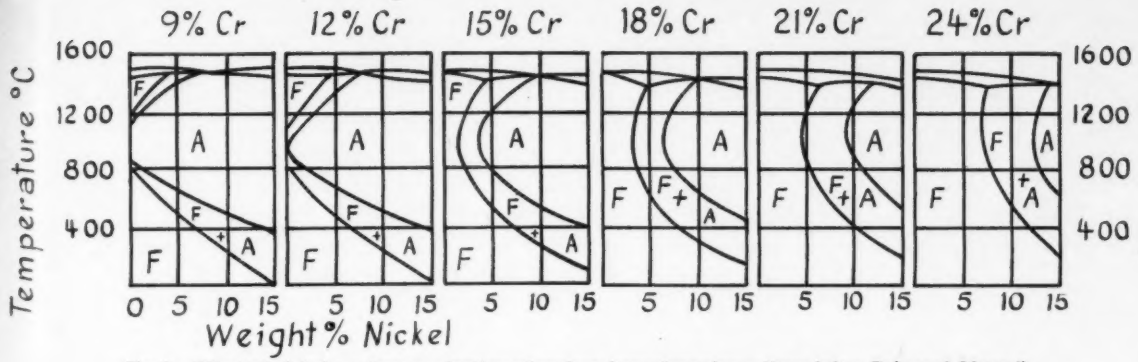


Fig. 3. Effect of nickel on the constitution of various iron-chromium alloys (after Bain and Aborn[6]).

that they become quite sluggish in the more useful alloys. For instance, an 18% chromium-8% nickel alloy which should, according to Fig. 3, be ferritic at room temperature, remains in a metastable austenite condition if cooled at even quite a moderate rate from the stable austenite region. The order of stability varies with nickel content, and below 7% nickel the austenite readily transforms to ferrite under the effect of cold work, whilst above 14% nickel the austenite may be regarded for all practical purposes as fully stable. Apart from its structural effects in stainless steel, nickel also exerts an appreciable effect on the resistance to corrosion when present in amounts greater than about 8%. It generally improves corrosion resistance and, more particularly, widens considerably the range of chemicals to which the austenitic steels have a reasonable resistance to attack. For instance, although nickel does not confer much additional protection against highly oxidising material such as nitric acid, it does improve considerably the resistance to non-oxidising corrosives and sulphuric acid and many organic acids. When the chromium content exceeds about 22%, nickel does not improve the passivity of the steels.

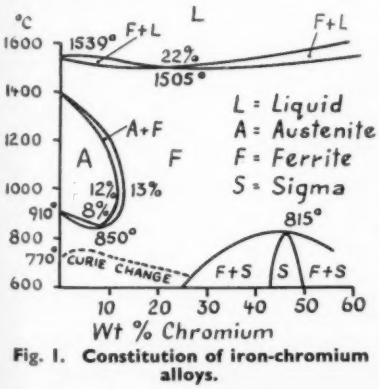


Fig. 1. Constitution of iron-chromium alloys.

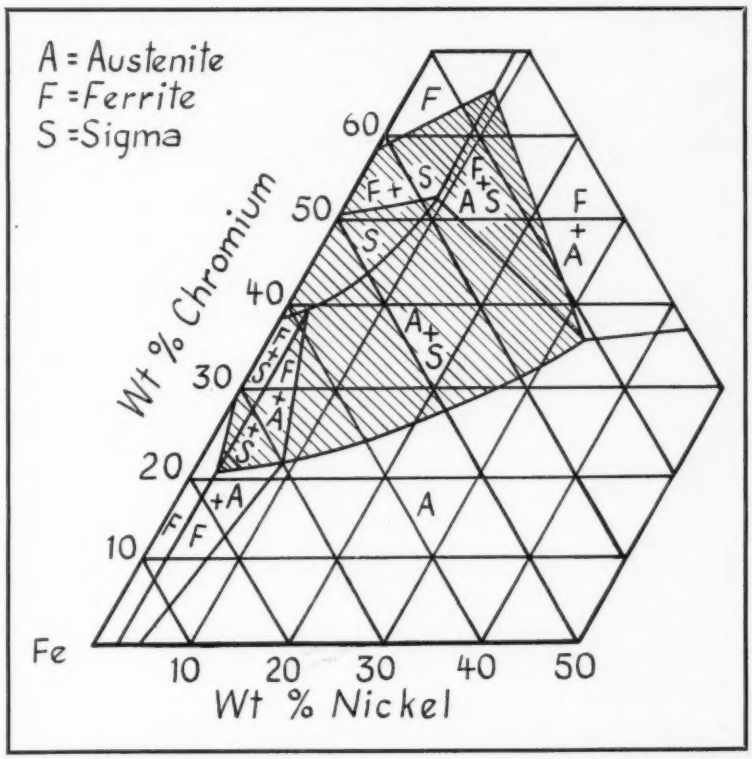


Fig. 4. Iron corner of iron-chromium-nickel constitutional diagram at 650°C. (after Schafmeister and Ergang[7]).

Sigma phase

In addition to the common phases ferrite, austenite and carbide which are found in most steels, some chromium steels also have a tendency to form a hard, brittle, non-magnetic phase which has been called sigma phase. Fig. 1 shows the regions in which this phase is formed in a straight iron-chromium alloy and Fig. 4[7] shows the area of sigma formation in ternary iron-chromium-nickel alloys. This phase generally forms after a comparatively long exposure of the steel in the critical temperature range, though it forms most rapidly from a mixed austenite-ferrite structure. One reference[8] reports the formation of sigma phase in as little as 10 min. exposure at 750°C., though generally a much longer time seems to be necessary. Sigma phase causes considerable loss of ductility and can, in a suitable environment, lower the resistance to corrosion.

From Fig. 2 it will be clear that one other phase change can occur in stainless steels containing carbon. There are regions in the constitutional diagram where carbides may form

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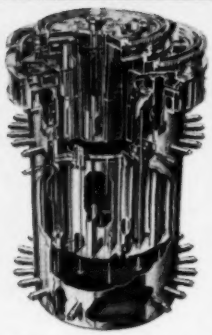

The fast breeder reactor at Dounreay, the most complicated stainless steel vessel ever made.

Absorption column of all welded construction made throughout in stainless steel.

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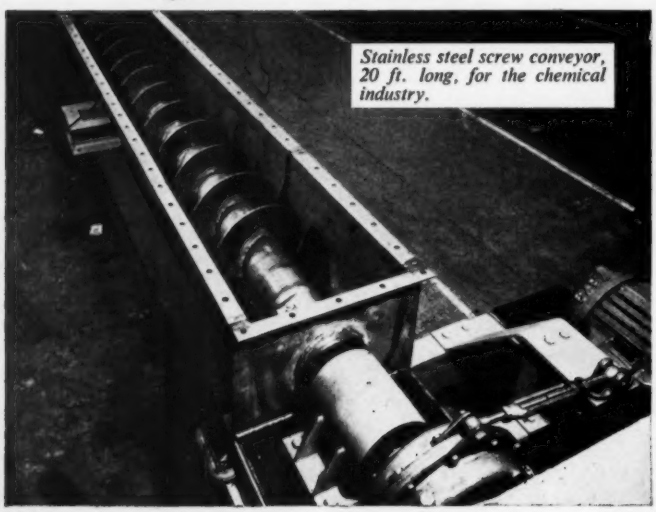
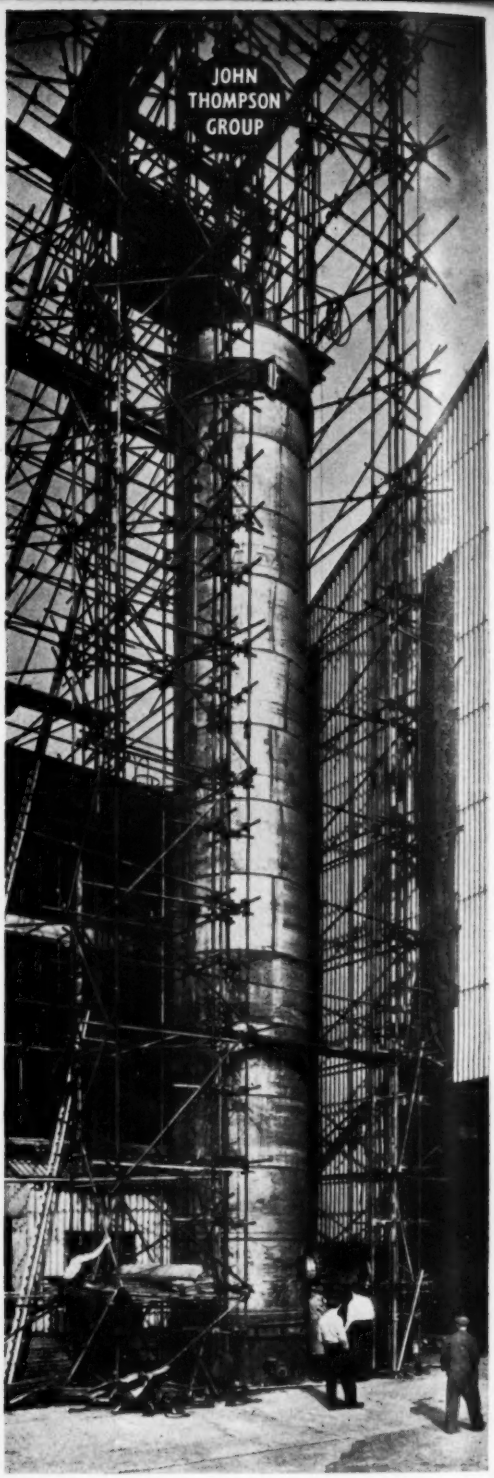


Stainless steel screw conveyor, 20 ft. long, for the chemical industry.



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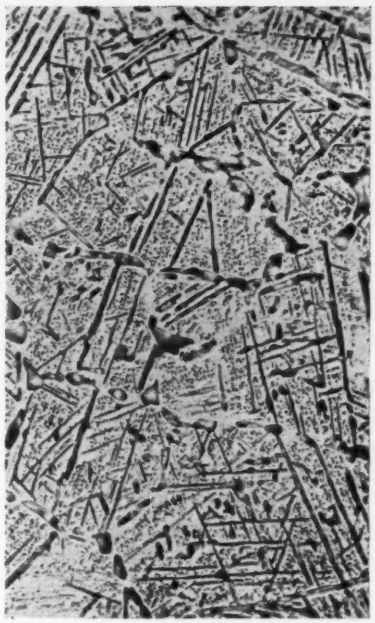
and, in practice, this can happen at grain boundaries in a region adjacent to welds, where the temperature has been raised to about 550 to 850°C. The carbide is usually of the form $Cr_{23}C_6$, so that locally, in the matrix adjacent to the carbide precipitate, there is quite serious depletion of chromium and hence a weakening of the passivity. In some corrosive media this can lead to local grain boundary corrosion which in welded austenitic steels has been called 'weld decay' and in martensitic steels used for cutlery has been termed 'band corrosion' because of its occurrence as a band some distance along the blade from the welded bolster. The simplest method of overcoming this kind of defect is to reheat the whole assembly into the stable austenitic region, say to 1,050 to 1,100°C., where the carbides should redissolve and remain in solution during the subsequent rapid cool. Some austenitic steel assemblies may be much too large to be accommodated in a reheating furnace or may distort too seriously in heat treatment, and in these cases one of two possible alternative procedures may be adopted.

The carbon content may be lowered to a value below which carbides would not form, but it is believed that for complete safety this has to be as low as 0.03% carbon. This would present considerable steel-making difficulties, though newer techniques of steel-making and the introduction of low-carbon ferro-chrome alloy might make it feasible. One other possible objection to the very low carbon austenitic steel is a suggestion that it might lead to instability of austenite and the possible formation of sigma phase. The usual method of ensuring that weld decay will not occur is to add titanium (four times carbon content) or niobium (eight times carbon content). These two elements are very strong carbide formers and form in preference to chromium carbide so that chromium depletion of the matrix is avoided. Stainless steels treated in this way are said to be 'stabilised'. It is customary to stabilise wrought forms of stainless steel with titanium and cast forms, *e.g.* castings and weldments, with niobium.

Stainless steels can be divided into the three main categories described above, *i.e.* ferritic, martensitic and austenitic, but within each grading there is a multiplicity of different compositions, varying in chromium, nickel and carbon content and also in some cases containing special additions, *e.g.* molybdenum for improved corrosion resistance or sulphur, selenium, zirconium and lead for free machining purposes. This has been brought about by the wide variety and severity of demands of the chemical and allied industries and, in fact, the subject of stainless-steel specifications has become a most complicated story as may be judged from the most excellent compilation of British and American standards by Kirk and Williams.[9] The problem of co-ordinating the British specifications was discussed at length by a special session of the Institution of Chemical Engineers in 1952[10] and a simplified scheme of presentation was incorporated in British Standard 1501-1506 : 1958.



Areas of sigma phase in a cast structure.

In view of the complexity of stainless-steel specifications it is clearly not possible to discuss all the variations in a single short article and therefore it is proposed to refer to only a few typical types. In fact, within a given group of steels the several variations do not differ greatly in properties.

Physical properties

A most comprehensive study of the physical constants of three typical stainless steels for the temperature range 0 to 1,300°C. was made by Dr. E. Griffiths and his colleagues at the National Physical Laboratories.[11] Typical values taken from this work are shown in Table 1. It will be noted that the density and thermal expansion of nickel-chromium austenitic steels are substantially greater than for ordinary mild steel, whereas the 13% chromium steels have appreciably lower values. The electrical resistivity of all the stainless steels is much higher than that of mild steel, with austenitic steels having the highest values. The thermal conductivity of the austenitic steels is about half that of the plain chromium steel which in turn is about half the thermal conductivity of mild steel.

Table I. Physical constants for typical stainless steels

(After Dr. E. Griffiths)

		18/8 *austenitic steel* (*Steel* 19)	13% *Cr chromium iron* (*Steel* 20)	13% *Cr martensitic stainless* (*Steel* 21)
Carbon content		0.08%	0.13%	0.27%
Chromium content		19.11%	12.95%	13.69%
Nickel content		8.14%	0.14%	0.20%
Density at 15°C. (g./c.c.)		7.916	7.745	7.741
Specific heat (g.cal./g./°C.)	50 to 100°C.	0.122	0.113	0.113
	250 to 300°C.	0.131	0.132	0.131
	450 to 500°C.	0.142	0.163	0.162
Thermal expansion coefficients	0 to 50°C.	13.88	9.86	9.62
	250 to 300°C.	18.52	12.30	12.26
	450 to 500°C.	19.92	13.20	13.32
Electrical resistivity (microhm cm.)	20°C.	71.0	50.6	52.2
	300°C.	91.6	76.9	76.9
	500°C.	102.6	93.8	93.5
Thermal conductivity (g.cal./cm./sec./°C.)	0°C.	0.038	0.064	0.060
	100°C.	0.039	0.066	0.063
	300°C.	0.044	0.067	0.066
	500°C.	0.052	0.065	0.065

The ferritic and martensitic alloys are, of course, magnetic, whilst the austenitic alloys are non-magnetic. The latter may become slightly magnetic in a cold-worked condition due to the formation of a small amount of ferrite from the metastable austenite.

A selection of typical mechanical properties for the main variations in types of stainless steel is shown in Table 2. This includes a few values for cast steels, from which it will be seen that equivalent tensile properties

to wrought steels may be obtained, except in regard to ductility and impact strength, which are appreciably lower. Figures are also included to show that, when the chromium content of a plain chromium steel exceeds about 14%, the material becomes brittle. This brittleness, in fact, exists only below about 200°C. If heated above this temperature the material becomes quite tough again. There is, however, a more serious form of embrittlement which occurs on heating for long periods in the region of 475°C. The precise nature of this form of embrittlement has not yet been fully explained, though it appears to be some form of precipitation embrittlement. It can be removed by reheating above 550°C.

The martensitic stainless steels clearly possess the superior mechanical properties and with them it is possible to obtain a combination of strength and toughness similar to that exhibited by high-grade structural alloy steel. It is therefore particularly suitable for mechanical components of a chemical plant.

The data for austenitic steels do not show any distinctive figures for stabilised types and, in general, it may be assumed that the addition of stabilising elements has little or no effect on the normal mechanical properties. However, apart from the conventional room-temperature properties, the austenitic steels have exceptionally good properties at low temperatures and high temperatures. The high-temperature properties of this type of steel have been discussed at length in the literature and it is well known that they are highly resistant to creep and to scaling at temperatures up to 800°C. Methods of presentation of creep data are always a subject of controversy, but Fig. 5 shows an approximate comparison of creep properties. The low-temperature properties have not as yet received the same degree of attention, but their importance is growing as sub-zero treatment comes into more general use. At temperatures down to −183°C. an 18/8 type of stainless steel shows a notable increase in tensile and yield strength with very little falling off in ductility. It is particularly noteworthy that the impact strength is retained down to these low temperatures. The following figures illustrate these points:

	Y.S. Tons/sq.in.	*M.S.*	*Elong.* %	120 *D* ft.lb.
Room temp.	21	40	56	114
−180°C.	43	85	42	100

It is important in this connection to consider the stability of the austenitic steel. If any transformation to ferrite or martensite should occur the steel would then be affected by the normal low-temperature embrittlement of ferritic structures. It has already been pointed out that in some of the austenitic steels plastic deformation will bring about a certain amount of transformation to martensite, but this can also be caused by the greater instability of austenite at low temperatures. Steels of rather higher nickel content are most likely to retain their stability, and it has been found that a small addition of manganese has a powerful effect in stabilising the austenite and thus preserving the notch toughness.

All the stainless steels are capable of being cold-worked and this is of importance in the cold-pressing or drawing of components, as well as in some cases providing higher tensile material. The austenitic steels work-harden rapidly, showing substantial increases in hardness, tensile strength, and yield point, although this improvement is necessarily accompanied by a lowering of the ductility and impact

Table 2. Typical mechanical properties of stainless steels

(On 1¼-in.-diam. bars except where stated)

Composition, %					*Heat °C. treatment*	*Mechanical properties*			
C	*Mn*	*Ni*	*Cr*	*Mo*		*Y.S.* tons/sq.in.	*M.S.* tons/sq.in.	*Elong* %	*Izod* ft.lb.
Ferritic steels									
0.10	0.30	—	13.0	—	850 F.C.	17	34	35	90
0.08	0.40	0.11	12.32	—	O.Q. 950, T. 750	30.6	38.5	29.5	100
0.07	—	—	13.3	—	A.R., T. 700°C.	—	38.6	34.0	110
0.09	—	—	15.5	—	A.R., T. 700°C.	—	32.4	38.0	10
0.09	—	—	22.8	—	A.R., T. 700°C.	—	28.2	21.0	3
Martensitic steels									
0.17	0.50	0.12	12.64	—	O.Q. 980, T. 750	36.4	47.0	27.5	90
0.22	0.45	0.14	13.6	—	O.Q. 1,000, T. 730*	43.1	49.5	25.0	81
0.25	0.8	—	13.0	—	O.Q. 980, T. 770†	29.0	42	29	15
0.15	0.23	2.50	16.86	—	O.Q. 1,000, T. 620	49.2	56.8	22.0	56
0.34	0.39	0.31	13.48	—	O.Q. 960, T. 725	40.0	48.0	29.0	102
Austenitic steels (bars between 1 to 2 in. diam.)									
0.1	0.3	8.0	18.0	—	1,100 A.C.	20	42	60	95
0.12	0.8	8.0	20.0	—	1,100 A.C.†	18	38	26	—
0.12	—	8.2	18.0	—	1,050 A.C.	16	54.8	56	120
0.12	0.68	8.7	21.2	—	1,050 A.C.	24.8	45.7	57	101
0.16	—	7.1	20.1	4.2	1,150 A.C.	33.5	46.1	46	118
0.1	0.7	9.0	19.0	2.5-4.0	1,100 A.C.	22	46	50	—
0.12	0.8	9.0	19.0	2.5-4.0	1,100 A.C.‡	20	44	25	—

*2¼-in.-diam. bar †Cast bar, 3 × 1¼ in. ‡Casting

'Staybrite' steel centrispun castings to be used for centrifugal basket centres. Made by Firth Vickers Stainless Steels Ltd.

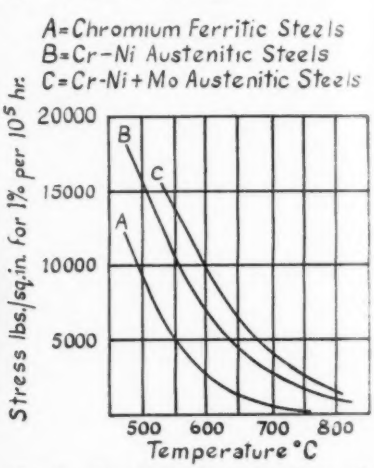


Fig. 5. Approximate composition of the creep.

resistance. For instance, an 18/8 steel having a tensile strength of about 42 tons/sq.in. and an elongation of 60% in the annealed condition would, after 50% cold reduction, have a tensile strength of about 85 tons/sq.in. with an elongation of only 15%. In the cold-worked condition the steel is partly magnetic. The martensitic and ferritic steels work-harden in a similar manner to an ordinary carbon steel. The modulus of elasticity for stainless steel is as follows:[12]

°C.	*Martensitic* 13% *Cr*, *tons/sq.in.* × 10^3	*Austenitic* 18/8,
20 ..	14.2	12.7
200 ..	13.4	11.7
400 ..	12.3	10.5
600 ..	10.8	9.4
800 ..	—	8.2

Corrosion properties

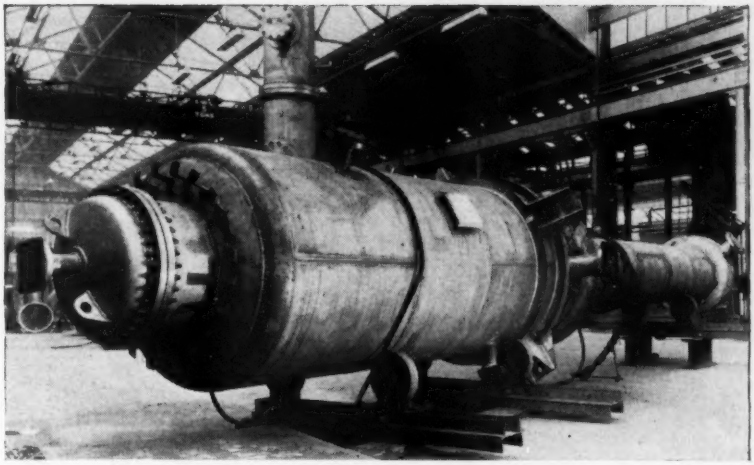
Four main types of corrosion have to be considered in relation to the performance of stainless steels. These are:

(1) General corrosion
(2) Intergranular corrosion
(3) Stress-corrosion cracking
(4) Pitting

General corrosion is prevented by the passive film previously referred to, and which in general is maintained under oxidising conditions. Sometimes only slight changes in environment will cause fluctuations in passivity and hence give rise to unpredictable variations in resistance to general corrosion. This is often found in the case of hot dilute sulphuric acid solutions where the presence of air or small amounts of an oxidising agent such as nitric acid can maintain passivity under otherwise corrosive conditions. On the other hand, hydrogen released from the corrosion of some other material in the system, or the presence of some other reducing agent, may be sufficient to destroy passivity. In borderline cases of this sort the addition of 2 to 4% of molybdenum to the steel will appreciably extend the range of permissible operation.

Intergranular corrosion is due to the precipitation of chromium carbides at the grain boundaries and has been referred to earlier. The formation of this grain-boundary carbide does not necessarily mean that the steel will be attacked by every corrosive medium, but when experience shows that this does happen then one of the practices previously referred to must be adopted.

Stress - corrosion cracking occurs when certain combinations of stress and corrosion act on the steel together.



Vertical cylindrical reaction vessel in wrought stainless-steel used in the oil industry. Made by Metal Propellors Ltd.

It is most likely to occur when heavily cold-worked steel has been used in the construction of the plant, but stresses induced in the plant during operation may also initiate this type of failure. Plant containing chlorides has been found to be particularly prone to stress-corrosion cracking, but there have been cases when aqueous hydrogen sulphide has had a similar effect. The possibility of this type of failure occurring may be minimised by annealing of the component before putting it into service, but care must be taken to avoid annealing in a temperature range where other harmful effects can occur, *e.g.* carbide precipitation or sigma-phase formation.

Pitting or localised corrosion occurs when small galvanic cells are formed, due to one or other of several possible causes, such as local contamination of the surface with abrasive, scale, mild steel, etc., or by stagnant conditions occurring at cracks, crevices or joints made with gaskets. The formation of local galvanic cells is encouraged by chlorides, with cupric chloride and ferric chloride being particularly severe. A molybdenum-bearing austenitic steel will best resist pitting, but steps should be taken to remove the cause of the pitting.

Typical corrosion effects by a representative selection of acids and alkalis are shown in Table 3. All three types of stainless steel listed in this table are resistant to the majority of aqueous solutions of salts, with the exception of certain halides, particularly the chlorides of aluminium, copper, iron, mercury, silicon and tin. Bromine, chlorine, fluorine and iodine all attack every grade of stainless steel as also do boiling sulphur, sulphur chloride, aniline hydrochloride, boiling sodium bisulphite, molten sodium carbonate and lysol. Most common hydrocarbon liquids do not attack stainless steels. Table 3 shows the effect of a single acid or alkali, but mixtures may behave differently. For instance, many boiling mixtures of sulphuric and nitric acids will attack even the molybdenum grade of austenitic steel. Similarly, although the steels are resistant to creosote, the presence of a small amount of salt in the creosote will render it corrosive. The effects of mixtures of reagents should always be tested and not assumed from the individual effects of the reagents.

Acetic acid has formerly been handled in wood, copper, or copper alloys, but increasing use has recently been made of stainless steel. Copper and its alloys have good resistance to acetic acid at all temperatures and concentrations provided that air or other oxidising agents are not present. In practice, however, it is difficult to comply with this condition which, in contrast, is favourable to the use of stainless steel, and generally an austenitic steel is now preferred. However, as the concentration approaches that of glacial acetic acid at high temperatures, some attack of stainless steel occurs and for these conditions a nickel-base alloy may be necessary.

Ammonium sulphate containing free sulphuric acid is a difficult mixture to handle. Chromium steels and 18/8 austenitic steels tend to be pitted and corroded by this mixture and, until the development of molybdenum types of stainless steel, it was usual to employ lead or occasionally silicon iron. Lead is affected by fatigue crack-

only FIRTH-VICKERS make

'Staybrite' F.M.B. steel has been the choice during more than 30 years for the jobs too difficult for the ordinary 18/8 stainless steels, such as marine conditions, certain dyeing solutions, and the production of phosphoric acid and its derivatives. It is much used in the production of synthetic fibres and plastics.

Technical information on the use of all Firth-Vickers steels, together with technical literature are always available on request.

FIRTH-VICKERS STAINLESS STEELS LTD., SHEFFIELD

is the only Company in Europe to devote its activities exclusively to the production and development of stainless and heat-resisting steels.

ing and silicon iron is brittle and requires much maintenance. However, an 18/10 austenitic steel containing 2 to 3% molybdenum has been found to be perfectly satisfactory.

Stainless steels, principally of the 18/8 tpye, have a wide application in the manufacture of high-purity chemicals such as pharmaceuticals and foodstuffs, where even traces of corrosion products cannot be tolerated. Although the corrosion resistance of the equipment is important, the effect of the corrosion on its life is usually less important than the effect of corrosion products on the materials being processed. The purity, colour and stability of the products may be greatly affected by the presence of trace quantities of metallic ions. For example, traces of iron affect Vitamin B_6 and therefore stainless steel is unsuitable for this product. Stainless steel is, however, satisfactory for processing Vitamin C, but traces of copper must be eliminated, since it promotes decomposition of the product. The

Table 3. Typical examples of the corrosion resistance of stainless steels

Reagent	*Type of steel*		
Acids	13% *Cr steel*	18/8 *Austenitic steel*	18/10 + *Mo steel*
Acetic acid	Resists all concentrations up to moderate temperatures. Attacked by boiling acid of all strengths	Resists all concentrations up to boiling point. Slight attack in boiling 100% acid	As 18/8
Acetic anhydride	Attacked by boiling acid	Slight attack in boiling acid	As 18/8
Boric acid	Attacked by boiling saturated solution	Resistant at all temperatures and concentrations	As 18/8
Chromic acid	Resists cold 5 to 10% acid. Attacked by hot or cold 50% acid	Resists cold 50% acid. Slight attack in hot 50% acid	As 18/8
Citric acid	Resists weak boiling acid. Attacked by hot or boiling 10 to 50% acid	Resists at all temperature strengths	As 18/8
Formic acid	Resists cold 1% acid. Attacked at all temperatures by strengths up to 50%. Resists 100% at all temperatures	Resists hot or cold 1% acid. Attacked by hot 10% acid. Attacked by hot 50% acid. Resists 100% acid at all temperatures	Resists hot or cold 1% acid. Attacked by boiling 10% acid. Resists hot 50% acid. Attacked by boiling 50% acid. Resists 100% acid at all temperatures
Hydrobromic acid Hydrochloric acid Hydrofluoric acid Hydrofluosilicic	Attacked by all concentrations	As 13% Cr	As 13% Cr
Nitric acid	Resists all strengths cold. Attacked by strong boiling acid	Attacked only by boiling concentrated acid	As 18/8
Nitrous acid	——	Attacked by cold dilute acid	As 18/8
Oxalic acid	Slightly attacked in cold acid. Attacked by hot and boiling acid	Resistant to cold acid. Attacked by hot and boiling acid	Resistant to hot acid but attacked by boiling acid
Phosphoric acid	Attacked by all strengths but less so in 60 to 90% range	Resists most strengths up to boiling point. Slight attack by boiling 40% and hot 60 to 90%. Attacked by 80% and at 110°C.	Resistant to all strengths up to boiling point but attacked by 80% acid at 100°C.
Sulphuric acid	Attacked by all concentrations	Slightly attacked by cold 5 to 10% acid and by hot and cold 85 to 95% acid. Attacked by hot or cold 15 to 75% acid	Resistant to hot or cold 5 to 10% acid and to cold 15%, 85% and 95%. Slightly attacked by hot 15%, 85% and 95%. Attacked by hot 20% and cold 40 to 70%
Sulphurous acid	Resists saturated solution at room temperature. Attacked by boiling solution under pressure	As 13% Cr	As 13% Cr
Tartaric acid	Resistant to 1% solutions. Attacked by 5 to 50% acid	Resistant to 1 to 50% acid up to boiling point	As 18/8
Alkalis			
Ammonia	Resists all strengths hot or cold	As 13% Cr	As 13% Cr
Caustic soda	Resists up to 30% solution hot or cold. Slightly attacked by hot 30 to 50% solution and by molten salt at 370°C.	Resists hot 30 to 50% solutions. Slightly attacked by molten salt at 370°C.	As 18/8
Caustic potash	Resists 25% solution up to boiling point	Resists 25% solution up to boiling point. Slightly attacked by 50% at boiling point. Attacked by molten salt at 360°C.	As 18/8

molybdenum type of stainless steel should be used for pickle liquors and sauces and it is desirable that this should be of an extra-low-carbon grade (0.3% C). One important advantage of stainless steel for this type of plant is the ease of cleaning, though in this connection the finish on the surface of the vessels is particularly important.

Choice of material

The major uses of stainless steels in the chemical industry are for:

(*a*) Vessels such as storage tanks, reactors, absorption and distillation columns and heat exchangers.

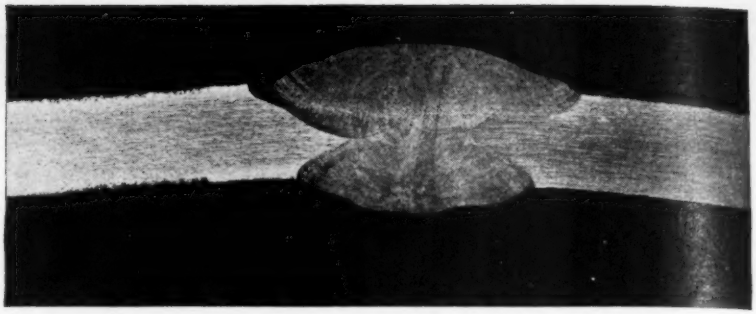
(*b*) Machinery such as pumps, fans, compressors, centrifuges, driers, coolers and filters.

(*c*) Materials handling equipment such as pipes, conveyors and road and rail tankers.

In choosing a steel (or any other metal) for the construction of chemical plant it is necessary to consider what the material will have to withstand in relation to stresses, temperature, chemicals, etc., how the plant is to be fabricated, and the form in which the material is available, *i.e.* sheets, bar, forgings, castings, strip, wire, tubing, etc. For many of the more specialised purposes in chemical plant, stainless steel is the only material which will fulfil the necessary combination of requirements. Even where a cheaper but less resistant material would be adequate it is still often preferable to choose a stainless steel because its use ensures minimum maintenance costs and least loss of production due to equipment failures.

Certain other materials have better corrosion-resisting properties in some circumstances but in general they are even more expensive than stainless steel. For instance, titanium resists all concentrations of nitric acid up to boiling point and has good resistance above boiling point. It is also more resistant to pitting and stress-corrosion cracking than stainless steel. It is, however, more expensive, not readily available in suitable forms and, where elevated temperatures and pressures are involved in the design of a vessel, titanium is at a disadvantage because of low design stresses. These disadvantages could disappear if titanium-clad steel should prove successful, and there is evidence that progress is being made in this direction.[13]

Undoubtedly, stainless steel is still a comparatively expensive material. An equipment in 18/8 austenitic steel would generally be three to five times as expensive as a similar mild-steel plant. It was once thought that stainless-clad mild steel might overcome the cost problem, but experience has shown that in present circumstances the saving in cost is not nearly as favourable as one would conclude from the costs of the individual mild steel and stainless steel. Added to this it has been found that fabrication of the clad plate introduces special problems which, though they can be overcome, add to the cost of using clad plate.



Intercrystalline corrosion adjacent to a weld made in ¼-in. thick stainless-steel sheet. The sheet on the left is unstabilised 18/8 steel and the sheet on the right 18/8 stabilised with titanium.

Nickel is one of the expensive ingredients in austenitic steels and efforts have been made to replace all or part of it with some cheaper alloying element. It is known that copper, nitrogen and manganese promote austenitic structures in a similar manner to nickel and all three have received some attention. Some 2 to 3% of copper improves the cold-working properties of an austenitic steel and enhances its corrosion properties, but it has a bad effect on the hot-working properties, and hence has found little use as yet. Much work has been done with nitrogen and manganese and, as a general guide, it has been found that nickel is twice as effective as manganese in promoting a stable austenite structure and that 0.2% nitrogen is approximately equivalent to 4% nickel. The corrosion properties of manganese-containing stainless steels are equal to 18/8 for mild to moderate conditions but tend to be inferior for highly corrosive conditions. Little is known at present about the corrosion properties of high-nitrogen stainless steels, but it is well established that the microstructure and mechanical properties compare favourably with conventional stainless steel. The commercial production of high-nitrogen steels poses special problems which have not yet been solved.

Continued development may bring to light new alloys, but at present it seems that expanding use will be made of stainless steels. The requirements for any new plant can only be established by close co-operation between the stainless-steel producers, plant designers, fabricators and plant users, and their combined efforts can be expected to reduce cost and operational problems.

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WHAT'S NEW

Plant • Equipment • Materials • Processes

CPE reference numbers are appended to all items appearing in these pages to make it easy for readers to obtain quickly, and free of charge, full details of any equipment, machinery, materials, processes, etc., in which they are interested. Simply fill in the top postcard attached, giving the appropriate reference number(s), and post it.

Ion exchange resin

A new series of ion-exchange resins has been developed by Rohm & Haas Co. (U.S.A.). The first of the series to become commercially available in the U.K. from Charles Lenning & Co. Ltd is *Amberlite* 200, a high-capacity, strongly acidic cation exchange resin. It is a sulphonated styrene-divinylbenzene copolymer, as are the standard resins, but extraordinary chemical and physical stability is claimed for it. This stability has been achieved by major changes in resin synthesis and is not related to the simple modifications hitherto employed for improving physical and chemical stability of ion exchange resins.

The resin is recommended for use in treating water supplies that cause conventional resins to de-crosslink; for the 'hot lime-zeolite' process; for rejuvenation of plating solutions; for sugar processing and in mixed-bed (Monobed) deionisation. It is also suggested for use in the treatment of highly aggressive solutions or where high operating temperatures are involved. **CPE 1538**

Glove box

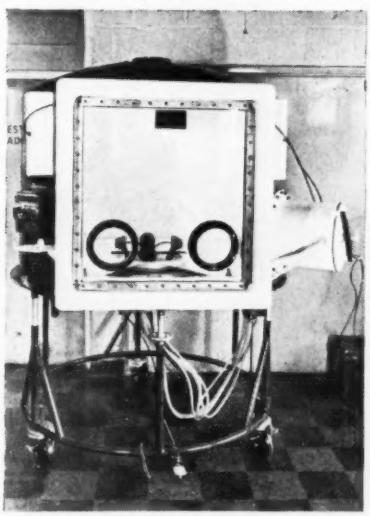
A glass-fibre rotary glove box is offered by Seton Creaghe Engineering Ltd. Designed for handling radioactive and other toxic materials, the *Secray* Mark III glove box is said to be also suitable for the assembly of small components under stringent dust-free conditions.

Corrosion resistance has been achieved and leakage rate reduced by moulding the box in a polyester-resin glass-fibre laminate. A weight reduction has also been obtained over the more conventional steel glove boxes.

In the standard model, two 6-in. glove ports are provided in the main window, giving access to an illuminated rotating table, and an 8-in. bag port is incorporated on the right-hand side for passing components into the box. Additional glove and window ports can be provided to suit customers' requirements.

Fitted at the centre of the dome-shaped roof is a 6-in. explosion port which is sealed by a rubber ball; when the box is pressurised above 1 in. water gauge the ball lifts, thereby releasing the pressure. A bag ring is provided, enabling the released gases to be evacuated *via* the laboratory extract system. A *Vokes* extract filter, with a quick-release clamp, is contained inside the glove box. The partial vacuum of 4 in. water gauge is maintained by means of an air suction ejector or vacuum pump connected to the outside of the box. **CPE 1539**

Oleo-pneumatic valves together with control cabinet.



Glass fibre rotatory glove box. This is one of the two supplied to the chemical section of the U.K.A.E.A. at Dounreay. Posting port on the right-hand side was a special requirement of the authority.

Oleo-pneumatic valves

A range of oleo-pneumatic auto-closing butterfly valves are offered by Boving Co. Ltd. They are said to incorporate several advantages over conventional butterfly and reflux valves, stemming from the asymmetrical blade design and the flexibility of the oleo-pneumatic package operating units.

The torque characteristics of the asymmetric blade make it possible to use the valve as a combined stop and non-return valve. Full flow in the normal direction exerts a closing torque on the blade at all angles from fully closed through approximately 84° to within 6° of the fully open position. At this point the torque reverses and the blade is then held in the fully open position as long as the flow continues in the same direction, until closed by the ram.

If the direction of flow reverses a closing torque is exerted on the blade at all angles from fully open to fully closed. The blade design also con-

tributes to drop-tight sealing.

The flexibility of the control system means that opening and closing times may easily be varied to suit pipelines operating conditions. The control can be varied for many different applications, including normal power-operated opening and closing, and power-operated opening and closing incorporating a 'cracked' open position. The control cabinet is weatherproof and can be used to operate the valve by push-button remote control. **CPE 1540**

PORTABLE BLAST CLEANER

A portable blast cleaning unit no larger than a small hand vacuum cleaner is offered by Hodge Clemco Ltd. The Educt-o-Matic *weighs 7 lb. and contains its own vacuum pick-up and dust extraction unit so that the only connection required is an airline. This should be $\frac{3}{4}$ in. internal diam., supplying 33 to 60 cu.ft./min. at a pressure of 90 to 100 p.s.i. There are no electrical connections.*

It is suggested for use in welding shops for cleaning welds or for cleaning before welding, in areas where dust would be a nuisance such as in canneries, and chemical plants, in highly mechanised factories and in areas that are difficult of access. **CPE 1541**

Glassed steel

The thermal shock resistance of *Pfaudler* glassed steel 59 is claimed to have been increased by 30% over conventional glassed steel under the most severe shock treatments caused by the meeting of unexpected or unavoidable temperature differentials. At a temperature of 450°F. it can withstand the thermal shock of ice water at 32°F. without any sign of chipping or weakening and, under certain conditions, an acid can be raised to 450°F. without damage.

The alkali constancy of the steel goes up to *p*H 11 at 212°F. This higher value reduces the permissible temperature limit up to 80°F. *p*H 14.

The microstructure of the steel, which the makers, Enamelled Metal Products Corporation, say is responsible for the improved thermal shock resistance, also allows lapping of nozzle faces on all nozzles up to and including 8 in. diam.

The steel is claimed to offer 20% more abrasion resistance and to give longer serving life. **CPE 1542**

Portable thermometer

The *Mavotherm*, a portable instrument for the measurement of temperatures in solids, liquids or gases, is said to be suitable for use in both laboratories and workshops for rapid measurement of ambient or static temperatures. Reading time is between 3 and 4 sec. and accurate to ± 2°C.

The instrument is battery operated and under normal load conditions, its 1.5 v. battery will last for nearly a year. It has two ranges, $-20°$ to $+ 90$°C. and $+ 90°$ to $+ 200$°C., and the scale readings are calibrated in degrees centigrade. Two calibrated probes designed for easy access to difficult locations are supplied.

It is manufactured by P. Gossen of Germany and marketed in the U.K. by Aveley Electric Ltd. **CPE 1543**

Hopper level switch

A diaphragm hopper level switch is offered by Firth Cleveland Instruments Ltd. It is designed to shut off the flow of granular or semi-solid material into a hopper, bunker or silo, when the level of the material reaches a height predetermined by the mounting position of the switch.

Type HS 1017/1 for open hoppers consists of an aluminium-alloy housing mounted on the wall or sloping floor of the hopper, the inside face being sealed by a strong synthetic-rubber diaphragm. When the material in the hopper presses against this diaphragm its deflection displaces a spring-loaded plunger, which in turn actuates a standard single-pole change-over microswitch. The pressure of material against the diaphragm can therefore be arranged to open or close a circuit for alarm or control purposes. The cover of the switch chamber is sealed by a gasket to provide weather-proof protection, whilst the diaphragm seals the working parts from any dust or liquid in the hopper. **CPE 1544**

Welding process

Rockweld Ltd. will shortly introduce the comatic automatic welding process, which is said to overcome the difficulties of fast vertical welding of relatively thin plates in mild and low alloy steels. It will weld plates down to $\frac{1}{2}$ in. thick. The principle of operation is that the wire and parent plate are melted by an arc, the weld being protected by CO_2 gas. The molten weld metal is contained by water-cooled copper shoes, located on opposite faces of the plate being welded and traversing upwards as welding proceeds.

Pfaudler glassed steel 59 at a temperature of 230°C. withstanding the thermal shock of ice water at 0°C. without any sign of chipping or weakening.

The machine consists of a vertical frame with two tracks which carry the welding head carriage. This carriage is equipped with a wire feed roll drive, a wire drum, a vertical traverse drive mechanism, an adjustable wire guide oscillation device, and fixtures for carrying the copper shoes. Controls and meters are incorporated in a cabinet attached on top of the carriage. The column, which is fitted with a lifting lug at the top, clamps directly on to the workpiece—the workpiece, in fact, supports the frame. The machine can be craned into an appropriate position on the workpiece. The structure is as light as possible consistent with rigidity.

In operation, the CO_2 arc gives the necessary side wall penetration with a small gap. When thin plates are being welded the wire is fed in centrally between the plates; for heavier plates the wire is made to oscillate across the thickness of the material. **CPE 1545**

Analysing uranium isotopes

A method of analysing the three major uranium isotopes via emission spectroscopy is offered by Baird-Atomic, Inc.

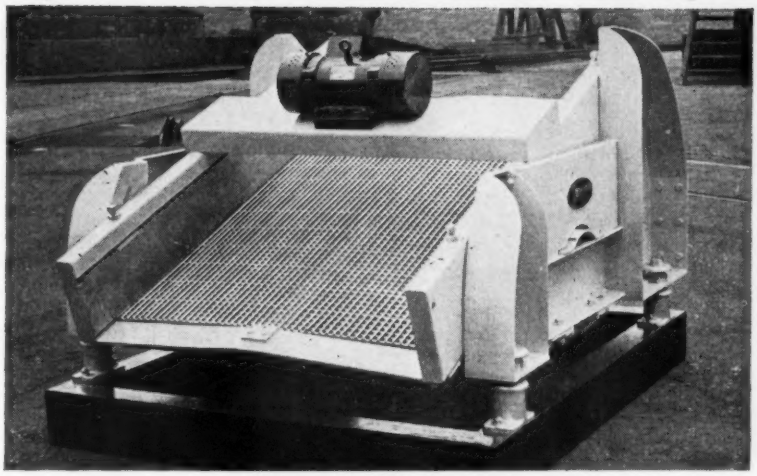
An instrument, which is a modification of a B/A direct reading optical emission spectrometer, makes possible quick, convenient analysis of uranium isotopes U-235, U-236, and U-238. Both enriched and depleted samples can be analysed. The ease and speed of the method should allow industries in the nuclear field to analyse their own uranium stocks without a large initial investment.

The company claim to have solved the major design problem inherent in such an instrument—the extreme proximity of the spectral lines emitted by these isotopes—by using the automatic optical servo monitor in the *Spectromet* model of their standard direct reading spectrometer in combination with a special diffraction grating and a three-prism beam-splitter. **CPE 1546**

Vibratory screens

High-speed vibratory screens, in which the drive and vibrator are incorporated into the motor, are offered by W. J. Jenkins & Co. Ltd. There is a saving in the horse power required and a wide range of adjustment to the amplitude of vibration is obtained by a simple operation, giving a maximum in excess of that obtained by normal methods.

There is an adjustable angle of deck from 5 to 30°. Single- and double-deck models are available in two sizes —the *Viking-Grantham Minor*, with a tray 4 ft. long and 2 ft. 7 in. wide, and the *Viking-Grantham Major*, with a 5-ft.-long tray 3 ft. 7 in. wide. **CPE 1547**



High-speed vibratory screen.

Urea resin

A fast-curing urea resin which will retain its gloss even on over-stoving is offered by British Resin Products Ltd. The resin, *Epok* U9040, is supplied as a solution in butanol and, when in stoving enamels, will give films which are claimed to possess excellent gloss retention and a degree of resistance to alkali superior to that of conventional resins.

The makers say that by stoving this resin for 15 to 20 min. at 120°C. the film hardness will be the same as that resulting from a conventional urea stoved for 30 min. **CPE 1548**

Pyrolitic graphite

What is believed to be the world's largest piece of highly heat-resistant pyrolitic graphite has been produced in the research laboratory of U.S. General Electric. The rectangular piece, $\frac{1}{8}$ in. thick, measures 17 by 31 in.

Pyrolitic graphite is stronger and more resistant to oxidation than ordinary graphite and has greater heat resistance. Its uses would be in missile nose-cone heat shields, rocket engine nozzles and the steering vanes of missiles.

It can be used in industry as a strong, smooth-surfaced material for hot-pressing dies, and as a heat-resistant material in melting crucibles for metals, ceramics and semi-conductors. It may also prove useful in nuclear reactors, in which graphite is used to slow down neutrons. **CPE 1549**

Diverter valve

A diverter valve which can be supplied for either manual or electro-pneumatic operation is offered by Thomas Robinson & Son Ltd. The valve has been designed for use in the company's *Pneu-Flow* pneumatic conveying system, for diverting powdered or granular material in blowing lines.

The valve is available in various bore sizes, and single solenoid valves with spring returns, or double solenoid valves which can remain in either position indefinitely, are available. An adjustable cushioned end-cap is fitted to valves required for very high-speed operation, and a solenoid control valve is also available which allows air to enter the cylinder at a faster rate. The valve consists of a cast-iron casing with an inlet bore and two outlet bores, the latter dividing at an angle of 40°. Steel sleeves, rolled into the cast iron of the cylinder body, enable a tight connection with the blowing lines to be made by the use of air seal couplings. A piston, located axially by end-caps, and radially by a stud, is fitted in the cylinder. The piston has two ports and by changing its position in the cylinder the conveying air and stock passes through either one or the other to the appropriate outlet bore.

Rubber 'O' rings are fitted to the piston to maintain a seal between the blowing lines and the cylinder ends, thus preventing air from the end-cap leaking into the blow-line. **CPE 1550**

New Books

Liquid-Metal Heat Transfer Media. Supplement No. 2 of the *Soviet Journal of Atomic Energy*. By S. S. Kutateladze, V. M. Borishanskii, I. I. Novikov and O. S. Fedynskii. Translated from Russian. New York: Consultants Bureau Inc.; London: Chapman & Hall Ltd., 1959. Pp. 149.

This work is an extraordinarily comprehensive review achieved within the compass of some 150 pages. It is claimed that it is 'devoted to problems of utilising liquid-metal heat-transfer media in nuclear power', but there is little doubt that it will prove to be valuable in the wider fields of engineering science and technology.

The book opens with a discussion on the thermodynamic properties of liquid metals, together with tabulated data on Hg, Bi, Sn, Pb, the alkali metals, and the alloys Na-K and Pb-Bi. A valuable feature recalls the great utility of the principle of similarity in the prediction of engineering properties. There follows a short discussion on binary heat engine cycles arranged to emphasise the special features, and hazards, which may occur in nuclear power plants.

For the most part, liquid metals do not wet the surfaces of the containers through which they are flowing and the question arises as to whether the normal hydraulic concepts on flow resistances may be applied. Tube roughness gives rise to vortex formation and it is this which influences the value of the hydraulic resistance rather than the common concept of liquid frictional forces at the surface. In general, and especially for smooth tubes, the usual hydraulic calculations may be made.

In turbulent heat-transfer processes, the relation of the distribution of temperature to the velocity distribution is described by the magnitude of the Prandtl number (Pr) and the nature of flow by the magnitude of the Reynolds' number (Re). All molten metals are characterised by a very low value of Pr, which indicates that the mode of heat transfer is influenced less by the degree of turbulence, the mechanism being rather that of molecular transfer. Experimental data are therefore analysed by correlation of the Nusselt group (Nu) against the Péclet number ($Pé$), which is the product (Re) (Pr). Martinelli (1947) and Lyon (1949) have shown by the methods of mathematical analysis that the following relationship should apply, namely $Nu = 7 + 0.025\,(Pé)^{0.8}$. On examination of a large number of experimental results the authors conclude that this equation may lead to a rather high value of Nu and present the equation in a modified form. It is stated that there is qualitative evidence that heat transfer is likely to be improved if the medium can be made to wet the transfer surface. A suitable method for this purpose is plating of some kind.

Heat transfer when the flow is around obstacles is discussed very fully, especially for flow across a flat plate and around a cylinder. The important feature observed is that there is a profound difference in the nature of the local heat transfer in the case of liquid metals as compared with, for example, a gas. It is characteristic that there is almost a constant heat transfer at the 'backwash region' of the cylinder.

The condensation of vapours and the phenomena of boiling are of considerable interest. It is shown that as Pr becomes very small ($<<1$) turbulence at the condensate film leads to an increase in the thermal resistance rather than to a lowering of this value as normally encountered with non-metallic liquids. That is, the principal resistance to heat transfer is to be found at a layer between the vapour and the condenser. It is because of this feature that the type of condensation has little or no effect on the heat-transfer process. The mechanism of boiling, as shown by a plot of heat flux against temperature difference, is almost identical with that associated with water. It is well known that the nature of the wetted surface profoundly influences the phenomenon, and that it may often be controlled by the addition of selected reagents to the liquid. A small quantity of Mg or Na added to mercury improves its contact with steel and consequently assists in the movement of the liquid-vapour mixture along the heating surface. If the surface is not wetted adequately, pellicular boiling occurs at almost any heat flow. Hg and Cd are liquids which do not wet the heating surface and the characteristic pellicular boiling is always observed. Where two-phase flow occurs, the hydrodynamic characteristics are almost identical with those associated with water-steam mixtures. The phenomena associated with boiling in tubes are considered fully.

Free convection is discussed on the basis of the well-known Lorentz equation, a modification of which is obtained by extensive correlation of experimental results.

Features of the design of heat-transfer equipment are outlined, and the effects of the liquid metal or alloy on the materials of construction are considered in great detail. Interesting in this regard is the phenomenon of diffusion bonding which occurs when two metals in contact are immersed in molten sodium at temperatures higher than 500°C., and also the effect of small quantities of oxygen in causing the solution of iron in mercury.

The work concludes with recommendations on methods of measurement of process variables, according to the experience of the authors.

A total of 81 literature references are given, of which 43 are Russian.

The nomenclature employed should present no difficulty to the technologist well versed in the general subject of heat transfer, although the value of the work as a whole would have been greatly enhanced, and the reading much easier, if tables explaining the symbols used had been inserted. The one annoying error noticed is the duplication of Fig. 5.2, which also appears as Fig. 5.3 with another caption! Despite these criticisms, this work will find an honoured place in libraries of heat technology and chemical engineering.

H. K. SUTTLE

The Radiochemistry of Thorium. By E. H. Hyde. 1960. Pp. vi + 70. $0.75 net.

The Radiochemistry of Fluorine, Chlorine and Iodine. By J. Kleinberg and G. A. Cowan. 1960. Pp. vi + 42. $0.50.

The Radiochemistry of Chromium. By J. Pijck. 1960.

United States Atomic Energy Commission Monographs. Available from the Office of Technical Services, Department of Commerce, Washington 25, D.C., U.S.A.

These are three further monographs in the series on the radiochemistry of elements, sponsored by the Subcommittee on Radiochemistry of the U.S. National Academy of Sciences National Research Council. Earlier numbers have been reviewed in this journal (1960, **41** (6), 266).

All the volumes follow a standard format, and it is quite remarkable how much useful information has been

compressed into such slim booklets. In each case, a review of the inorganic and analytical chemistry of the element is presented in addition to detailed consideration of its radiochemistry. Each volume contains extensive lists of references.

There are many obvious errors in the monograph on the radiochemistry of chromium, which should have been observed in the course of proof-reading. However, the three new volumes are to be strongly recommended. Most radiochemists will wish to acquire the complete series of monographs and many other scientists will find that the purchase of individual volumes is justified.

D. F. C. MORRIS

Penetration of Charged Particles in Matter. Edited by Edwin A. Uehling. Publication 752, National Academy of Sciences, National Research Council, Washington, D.C. Pp. 168.

Within modest compass this publication offers a vast array of highly important information on an important subject, the highlights of the Gatlinburg Conference of 1958. About 25 talks were centred on the entry of charged particles into matter, and ranged from the reliability of experimental data to new approaches to the theoretical description of energy loss mechanisms.

Stopping power and ranges of low-energy particles have not been very satisfactorily determined, especially for alpha particles and the heavier ions, for which practically no measurements have been made. The absence of adequate theory for low energies makes even more difficult the synthesis of results, although the *K*, *L* and *M* shell-binding energy corrections have been applied. Discontinuities in data indicate that the mean ionisation potential is not monatomically variable with atomic number. For *Z* values above 14, the ionisation potential divided by atomic number, *i.e.* I/Z, changes very little, but the earlier value of 14 for this ratio is now considered to be unreliable, a truer value being between 14 and 11.5. The most striking fluctuations occur in the transition series, Ca to Ni, and Th to Pb.

Chemical binding obviously affects stopping power, since three C_2H_2 molecules have a stopping power considerably greater than the benzene molecule (C_6H_6) below energies of 100 KeV.

Nuclear track emulsions are the medium for which most reliable measurements of stopping power and range have been made, and the range-energy curve for a standard emulsion is, perhaps, the most important calibration relation required in high-energy physics. Barkas, of Berkeley, presents a valuable contribution on this.

A tentative approach to a theory of stopping power is made by Lindhard and Scharff, of Denmark, whose results confirm the consistency of their statistical type of approach.

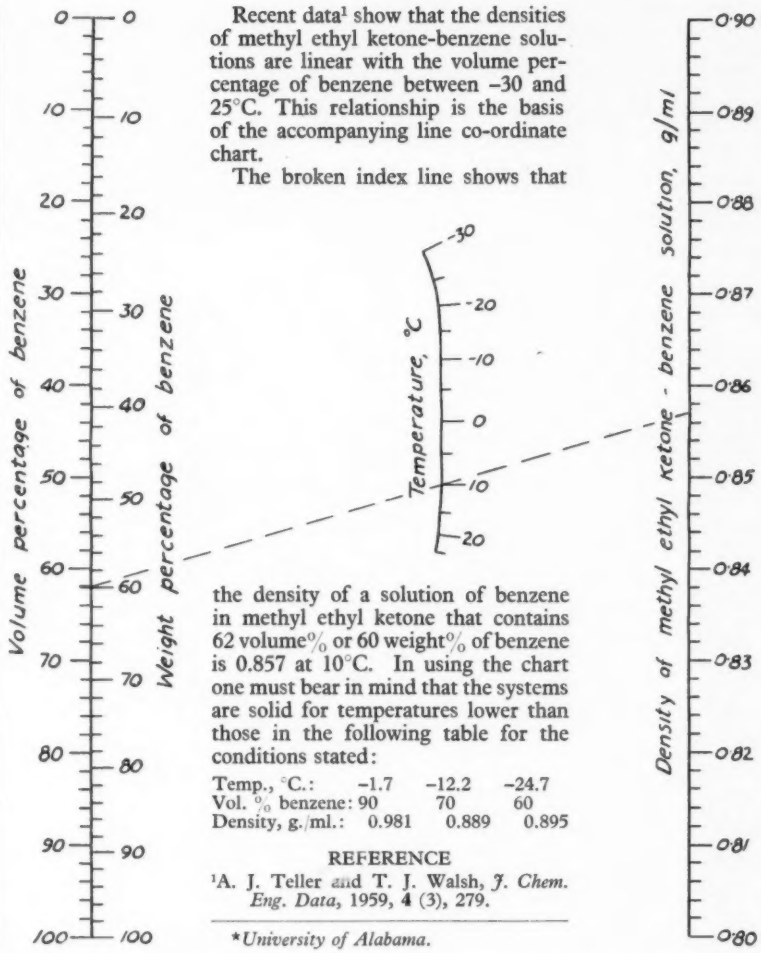
Seven papers centre around collisions in which the charge of a moving gas ion changes. It is clear that more work is required on double-electron captures. Evidence is produced that charge-changing processes occur in auroral displays, low-energy electrons being involved in the active rays, and protons in the arc.

Hasted, of University College, London, describes work on the coincidence counting methods for studying inelastic ionic collisions and his method can find uses especially in the study of the ratio of stripping to ionisation cross-sections. So much in this book is important that a hasty assessment is out of the question. It is inspiring to see, however, that, although so much progress has been made in this difficult field, there is still plenty of scope for the research workers of the future and, indeed, of the present.

F. R. PAULSEN

Densities of Methyl Ethyl Ketone-Benzene Solutions

By Prof. D. S. Davis*



Recent data[1] show that the densities of methyl ethyl ketone-benzene solutions are linear with the volume percentage of benzene between –30 and 25°C. This relationship is the basis of the accompanying line co-ordinate chart.

The broken index line shows that the density of a solution of benzene in methyl ethyl ketone that contains 62 volume% or 60 weight% of benzene is 0.857 at 10°C. In using the chart one must bear in mind that the systems are solid for temperatures lower than those in the following table for the conditions stated:

Temp., °C.:	–1.7	–12.2	–24.7
Vol. % benzene:	90	70	60
Density, g./ml.:	0.981	0.889	0.895

REFERENCE

[1]A. J. Teller and T. J. Walsh, *J. Chem. Eng. Data*, 1959, **4** (3), 279.

**University of Alabama.*

NUCLEAR NOTES

Nuclear ship control

Dangers arising from collision of nuclear-powered ships might mean the establishment of international shore control stations for certain congested areas, such as the English Channel. This was advocated by Mr. R. Y. Bell, chief nuclear engineer of Yarrow & Co. Ltd., when he spoke at Paisley Technical College recently. Suitable control systems might be worked out on the lines applying on international airline routes.

Since only large ships were meantime being considered for nuclear propulsion, it was possible to keep the installation well away from the ship's side and to provide substantial protection by collision barriers to absorb the shock of impact and protect the reactor. Even so, there had been exceptional cases where large ships travelling at high speed had collided and their hulls had been heavily penetrated. This could become a serious hazard in a nuclear ship, and provision would require to be made against such a contingency.

Soviet reactor

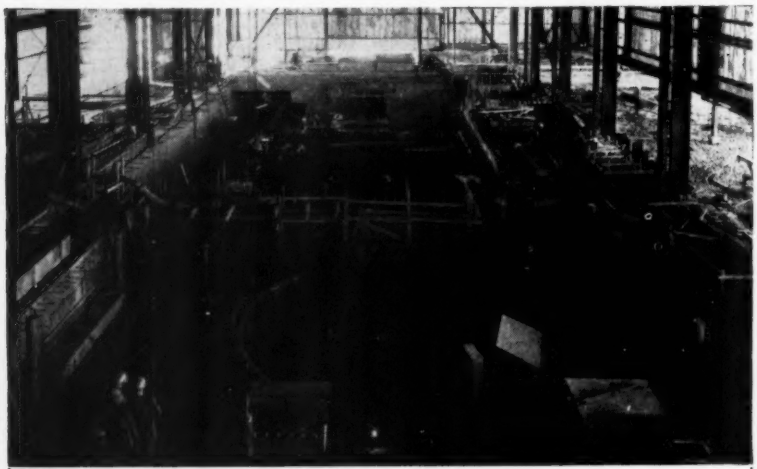
The assembling of the reactor set has started at the Beloyarsk atomic power station which is under construction in the Urals. The station's capacity will be 200,000 kW.

The reactor is a graphite cylinder, over 30 ft. high and 29½ ft. diam. Inside it are 998 channels with nuclear fuel. Charged with uranium, the reactor can generate energy continuously for two years. The reactor is surrounded by a water-filled reservoir made of iron as a protection from radioactive radiation. It also has a protective reinforced concrete layer 3¾ ft. thick, and will be controlled from an underground panel 23 ft. below the surface.

Radiation measurements

About 200 scientists from 28 countries met in Vienna recently at a symposium on radiation dosimetry organised by the International Atomic Energy Agency. Representatives of the U.N. Scientific Committee on the Effects of Atomic Radiation, the International Commission on Radiological Protection, the European Organisation for Nuclear Research, the European Atomic Energy Community, the Organisation for European Economic Co-operation and the World Health Organisation also attended the meeting.

Explaining the purpose of the meeting, the I.A.E.A. director-general, Mr. S. Cole, in his inaugural speech, pointed out that with the rapid increase in the uses of ionising radiations the problem of accurate radiation measurements had become especially important. Radiation dosimetry, however, already covered such a large field that it was not possible to deal with more than a few selected topics at one scientific meeting. The aim of the present symposium was not so much the description of a large number of measuring instruments as a discussion on the methods used. Special emphasis, Mr. Cole said, would be placed on those problems which had become important in the context of recent developments. Apart from discussing the measurement of small doses and dose rates, the meeting also considered the techniques of measuring extremely high doses which were necessary in certain scientific investigations and technological applications. Furthermore, reactors produced a mixture of neutron and gamma radiation and a number of papers at the symposium dealt with methods of measuring this mixed radiation by separating its components in such a way that the amount of energy absorbed could be deduced.



NEBRASKA PLANT

Nuclear reactor vessels will be placed into the cavity liner shown in the centre foreground of this photo of the Hallam Nuclear Power facility, being built near Hallam, Nebraska. Atomics International is building the sodium graphite reactor for the 75,000 kW. nuclear power plant. At either side of the cavity liner are tunnels for primary sodium heat transfer piping. Fuel and reactor components storage cells are in the centre and background. Consumers Public Power District of Nebraska will operate the completed plant, part of the U.S. A.E.C.'s power reactor demonstration programme, which is scheduled for start-up and initial operation in 1962.

Vacuum welding

Electron beam vacuum welding—developed by a G.E.C. engineer at the Hanford, U.S.A., laboratories—is being used to make improved Hanford nuclear fuel elements. The new system was needed to overcome problems connected with welds in metals used in a reactor.

Faults in some cases develop in a weld because of atmospheric contamination from oxygen and nitrogen. To some extent, this problem is solved by welding reactor metals in a shielded atmosphere of inert gas such as argon or helium. In certain cases, however, inert gas welding can cause contamination and other undesirable effects.

Reactor simulator

A reactor simulator has been designed and constructed for the reactor school, A.E.R.E. Harwell. It will be used for instruction in the theory and practice of reactor control.

The control desk of the simulator is basically similar to that of a nuclear power station but is capable of registering accurately power levels with the range of 0.1 W. to 100,000 MW., so that experience in handling all types of reactors may be obtained. The temperatures of the uranium and graphite are computed and recorded continuously, push-button controls are employed throughout and an unusual feature is the digital display of the position of fine and coarse control rods.

The equipment was designed and constructed by General Precision Systems Ltd. to the requirements of the school.

Condenser bank model

A low voltage working model of the condenser bank used for controlled fusion research at the Atomic Weapons Research Establishment, Aldermaston, has been presented to the Royal College of Science and Technology, Glasgow. The apparatus will be employed in low-energy experiments with plasmas. It was first exhibited at the second International Conference on the Peaceful Uses of Atomic Energy in Geneva.

The device is essentially a low-inductance bank of 200 condensers firing through the same number of spark gaps in parallel to give an extremely fast build-up of current in discharges through deuterium gas contained in a straight quartz tube. It is a low voltage model of the condenser bank which is in use at A.W.R.E. for thermonuclear research.

U.S. Atomic industry sales

The U.S. atomic industry is estimated to have sold and delivered approximately $1.5 billion worth of nuclear reactors, components, materials and services to government, industry and overseas markets during the five-year period, 1954 to 1958. This estimate is projected from $933 million worth of sales reported by nearly 200 companies participating in a survey conducted by the Atomic Industrial Forum, the association of the nuclear industry, and detailed in a new report entitled, 'Business Statistics on the Atomic Industry, 1954-1958'. The report also gives details on research and development expenditures, capital investment and employment.

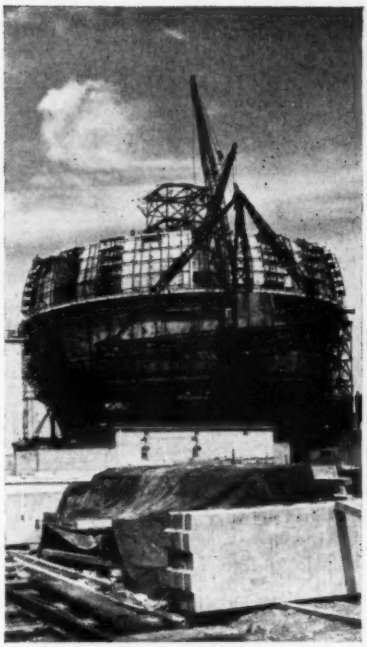
The reported or estimated sales totals do not include equipment and services for the nuclear weapons programme or propulsion reactors for the naval and aircraft programmes, or most of the costs associated with the operation of government-owned research, development and production facilities.

Enriched uranium manufacture

Mallinckrodt Nuclear Corporation have received a contract from Argonne National Laboratory, for 1,200 kg. of highly enriched uranium metal.

The major portion of the metal will be used in the core of the fast reactor ZPR-6. This is a new experimental reactor designed to investigate various fuel configurations and the effect of these fuels on various materials being considered for use in reactor construction.

Production has already begun at Mallinckrodt's Hematite plant. A new process that converts the raw material uranium hexafluoride directly into uranium tetrafluoride and then into metal by conventional means is being used. One of the benefits claimed for the new process is purity. It is said to average 99.95%, which is above the specified purity requirement in the contract.



Construction work in progress for the advanced gas-cooled reactor at Windscale. The ultimate objective is to gain operating experience of carbon dioxide - cooled, graphite - moderated power reactors.

Structural Problems in Reactor Engineering

(*Concluded from page* 356)

In view of the results obtained, it was subsequently decided to investigate the decay of the oscillatory solutions, and in particular the bending stresses near the various junctions. It was clear that these additional calculations ought to be done on a digital computer, and accordingly the general algebraic expressions for the membrane and bending stresses (but not deflections) were programmed for EDSAC II, the digital computer at Cambridge. The programming time involved was about seven working days, and the programme was used to produce tables of stresses in the cylinders and sphere segments at 2 to 3-in. intervals up to distances of about 3 ft. from the various boundaries. It was found that at such distances the oscillatory bending stresses had been reduced to a small percentage of their boundary values. The total computing time was only a few minutes.

Conclusions

The examples described in this article are merely a few of the many problems which face the structural engineer in the design of a reactor. To solve these problems the engineer may resort to complicated theoretical analysis. If he does, he is very likely to use a digital computer at some stage in his work, and this article has shown how these machines have made possible long and complicated analyses. However, the most complex mathematics is useless if the basic assumptions are wrong, so that tests on scale models form an equally valuable method for arriving at safe and economic designs.

The work described in this article was done at Cambridge on behalf of the atomic energy division of G.E.C. Ltd. by the author and his colleagues, Dr. F. A. Leckie, Dr. A. H. Chilver and Miss G. M. Christ, under the general direction of Prof. J. F. Baker. The article is published by permission of G.E.C. Ltd. and the South of Scotland Electricity Board.

REFERENCES

[1] *Nuclear Eng.*, 1957, **2**, 51.
[2] E. Lightfoot and F. Sawko, *The Struct. Engr.*, 1960, **38**, 79.
[3] R. K. Livesley, *Nuclear Eng.*, 1960, **5**, 116.
[4] F. A. Leckie and R. K. Livesley, 'The stress analysis of a containment vessel subjected to lateral loads'. Paper presented at a symposium on nuclear reactor containment buildings and pressure vessels, Glasgow, May 1960.

Company News

Dust-free area

The Fisher Governor Co., a member of the Elliott-Automation group, has built at its Rochester factory a dust-free area for the assembly of the special valves and automatic fluid control equipment it is producing for secret work in the nuclear field.

The duty for which these valves are required is such that they must be able to operate for a period of at least twenty years without attention. To meet this requirement all the assembly work must be carried out under clinically clean conditions. Therefore, a special air conditioning plant has been installed which not only cleans the air but controls its humidity and temperature to within close limits.

The room is entered through an air lock, where the operators put on special clothing. Once in the clean area only special tools, which are kept there permanently, may be used on the assembly work. Immediately the equipment has been inspected after test and passed for delivery all apertures are sealed off and the whole unit is encased in a polythene bag and purged with an inert gas.

Research centre

At the end of May the Secretary of State for Scotland, the Rt. Hon. J. S. Maclay, opened the Balfour group research and development centre at Leven, Fife.

The building houses a series of laboratories designed and made by the group for the carrying out of research and development work in the design and operation of chemical process plant—with a wide range of industrial applications—and techniques of use and manufacture of materials of construction.

Integrated with the laboratories are comprehensive installations of pilot plant, encompassing the main types of processes and equipment, to demonstrate applications on clients' raw materials.

Complete processing systems can be analysed, tested and evaluated in terms of size, output, operation, number of stages involved, operating temperatures, flow arrangements and so on, so that the most efficient conditions for the production of a successful end-product will be ensured before expense is incurred on installing full-scale plant.

The main chemical laboratories specialise in corrosion research, physical chemistry, metallography, chemical analysis, enamel and ceramic testing and specimen preparation.

Cyclic ketones

During 1959 the main plant expansions undertaken by Howards of Ilford Ltd., at Ilford, were the construction of a phthalic anhydride plant and the rebuilding of the recrystallisation stage of the aspirin plant.

The major projects for 1960, all of which are now well advanced, are the rebuilding of the remaining section of the aspirin unit, the rebuilding on a considerably increased scale of the unit producing cyclic ketones, mainly cyclohexanone and methylcyclohexanone (*Sextone* and *Sextone B*) and a substantial extension to the production facilities for *Sorbitol* 70% syrup. All three projects are planned to be completed before the end of February 1961.

£ s d

CHEMICAL PLANT COSTS

Cost indices for the month of June 1960 are as follows:

Plant Construction Index: 181.2

Equipment Cost Index: 170.6

(June 1949 = 100)

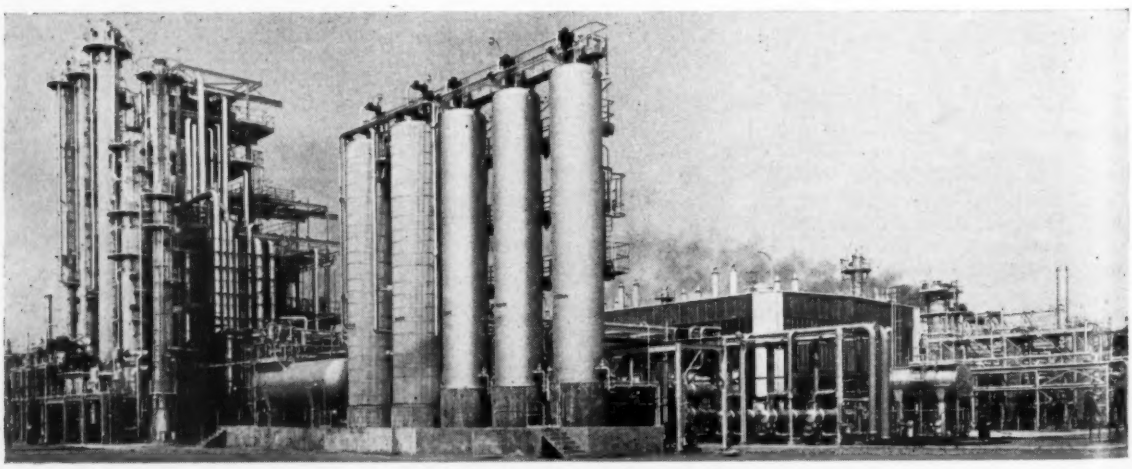
£ s d

Pigments for plastics

In little more than two years Acheson Dispersed Pigments Co. has outgrown its plant capacity at Dukinfield, where pigment masterbatches and concentrates for the plastics industry are manufactured. To keep up with the demand for their services, especially from polyethylene and polystyrene producers, the company are extending the works to provide space for new plant.

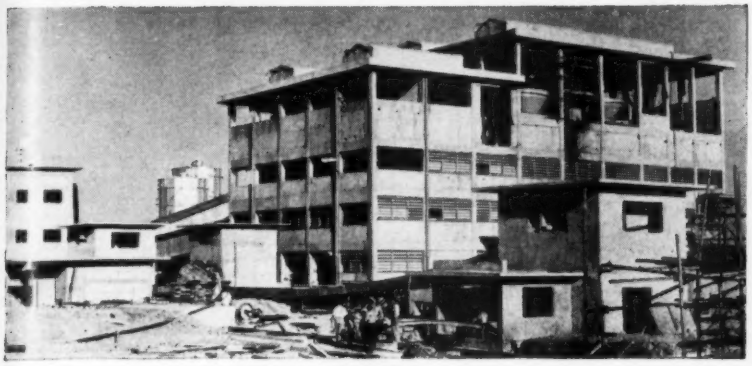
Ethylene plant

British Hydrocarbon Chemicals Ltd.'s third ethylene plant at Grangemouth, Scotland, has been completed ahead of schedule and the plant is already on stream. It is believed to be the largest of its kind outside the U.S.A. and will more than double the existing capacity of the company's two previous ethylene plants, which were first operated in 1951 and 1956 respectively.



Third ethylene plant at Grangemouth.

World News



INDIA

The coal washery, now in operation at the Durgapur steelworks, is situated on the coal handling plant area. The building is a concrete structure, designed to suit local climatic conditions.

The washery has a capacity of 360 tons/hr., is equipped with an extensive water clarification unit and was designed and built by Simon-Carves Ltd., one of the 13 companies of the British Consortium, Indian Steelworks Construction Co. Ltd.

CANADA

Hydrodesulphuriser

Shell Oil Co. of Canada Ltd. will begin construction of a distillate hydrodesulphuriser at its Montreal East refinery. Total cost of the project, including the addition of necessary auxiliary equipment, is about $3 million (over £1 million).

The construction is to start early in July with completion scheduled for December of this year. A contract for the work has been awarded to Canadian Bechtel Ltd.

The operation, called 'trickle-phase' hydrodesulphurisation, employs a patented Shell process designed to reduce the sulphur content of distillate in the production of fuels of still higher quality for future diesel, heating oil and aircraft applications.

HUNGARY

Chemical expansion

Hungary's chemical industry has made progress since the end of the war. As compared with 1949, its output has grown by 465% in ten years, and by the termination of the five-year plan the rise is scheduled to attain 550%.

Visitors to the pavilion of the Budapest Industrial Fair held recently, were able to form an idea of the rapid advance in Hungary's bauxite mining and alumina production. Compared with figures for 1945, bauxite mining has increased to 1,600%, alumina production to 4,000%, and aluminium metallurgy to 1,900%. Samples of red bauxite, the elementary raw material of the aluminium industry, and of red mud, employed chiefly as a dye, were put on show at the pavilion. The latest product of the Hungarian aluminium industry is the metal gallium, a rare metal used by the pharmaceutical industry and in vacuum technique.

SWEDEN

Nuclear fuel elements

AB Atomenergi, the Swedish nuclear power development company, is to produce fuel elements for the Halden reactor, Norway. The raw material will be uranium oxide containing 1.5% uranium-235, imported from the U.S.A., which will be sintered into cuts and encased in zirc-alloy tubes. The elements will be tested in the RO reactor at Atomenergi's Studsvik research centre, and delivery to Norway will follow in the spring of 1961.

ITALY

Petrochemical expansion

The last few years have brought unprecedented growth to the Italian petrochemical industry. Synthetic fibre production has more than doubled since 1955, while synthetic resin production has leapt by 71%, refinery output by 30%, and synthetic ammonia by 53.6%. Exports of plastics, synthetic resins, and synthetic rubber have kept pace with this phenomenal growth. Several new petrochemical plants are already under construction. In Brindisi, work was started last March on what will be the biggest such plant in Europe, in which Montecatini plans to invest 50 to 60 billion lire. In Sicily, some 50 new chemical plants have sprung up, including seven large plants turning out fertilisers and plastics. Among these are Sincat, owned jointly by Edison and Monsanto Chemical, and Celene, built by Edison and Union Carbide.

NORWAY

Atomic energy essential in 20 years

Norway's waterpower resources will be almost exhausted in 20 to 25 years' time, and if she does not make very persistent efforts to develop atomic energy she may find that she will then be considered to be one of the underdeveloped areas of the world. This was said recently by the director of Norwegian Atomic Energy Institute. Norway must try to develop a new type of reactor which produces cheaper electricity than the present one, and the prospects for this are good, he said. The cheapest electricity in Norway today is produced at a price of 2.5 öre/kW. (a little more than ¼d.), whereas electricity produced by atomic energy costs 5 to 6 öre (¾d.). He was confident it would be possible to reduce this price of atomic electricity to 3 öre in 20 years.

Steel plant for Narvik

Plans for a new steel plant at Narvik, which would use Swedish iron oxide from Kiruna on the other side of the frontier, are now taking shape. Based on utilising Norwegian coal or coke, the plant will produce a steel powder which will be exported pressed into blocks.

One German concern has already offered to buy 10 years' production output estimated at 250,000 tons p.a. The financial side of the project is now under consideration, and if all goes well construction work may start next spring.

UNITED STATES

Plastics exhibition

A big plastics exhibition will be held in New York City's Coliseum in June of 1961. The 9th National Plastics Exposition is sponsored by the Society of the Plastics Industry, Inc., a trade and technical society representing 1,150 companies and more than 2,400 individuals in the plastics industry throughout the United States, and 28 other countries. Chairman of the Exhibition Committee is R. F. Elder, President, Plax Corporation.

Let's l k at the facts

When considering latest developments in electro-precipitation

SIMON-CARVES LTD. are responsible for

The First PRECIPITATOR in Great Britain

for LD converter gas cleaning — in fact, the first in the world for the LD/AC method of oxygen application. Installation is in progress at the Ebbw Vale works of Richard Thomas & Baldwins Ltd.

The First PRECIPITATOR in Europe

for oxygen-process, open-hearth furnace gas cleaning, now installed at Scunthorpe for Appleby - Frodingham Steel Co; two further units are on order. The Steel Co. of Wales have also ordered two units.

The First PRECIPITATOR in the World

on a 550 MW pulverised fuel fired boiler unit. It is being installed at Thorpe Marsh Power Station on a boiler built by International Combustion Ltd.

Simon-Carves Ltd. have produced a new brochure, Steelmaking and Electro-Precipitation, for those with gas cleaning and dust collection problems. To obtain a copy, write to CPP Division (C.P.E.) at the address below.

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CPE Diary

AUGUST 16 Lecture on the **physical nature of plastic flow,** by Dr. J. J. Gilman, under the auspices of the Metal Physics Committee of the Institute of Metals at the Institute's headquarters, 17 Belgrave Square, London, S.W.1.

AUGUST 31 TO SEPTEMBER 7 Annual meeting of the **Association for the Advancement of Science** to be held in Cardiff. Details from the society, 18 Adam Street, Adelphi, London, W.C.1.

AUGUST 31 TO SEPTEMBER 11 St. Erik's **Trade Fair** in Stockholm. British participation in fair organised by Trade Fairs and Promotions Ltd., Drury House, Russell Street, Dury Lane, London, W.C.2.

SEPTEMBER 6 TO 17 Conference on the **uses of radioisotopes in the physical sciences and industry** in Copenhagen, Denmark. Sponsored by the International Atomic Energy Agency and U.N.E.S.C.O. Information from I.A.E.A., 11 Kartner Ring, Vienna 1.

SEPTEMBER 11 TO 25 International **trade fair** at Brno, Czechoslovakia. Details from Brno Trade Fair, Vaclavske namnesti, Prague, Czechoslovakia.

SEPTEMBER 13 TO 16 **Instruments and Measurements Conference** in Stockholm. Details from Mr. H. von Koch, Royal Institute of Technology, Stockholm 70, Sweden.

SEPTEMBER 20 TO 23 **Course for directors and senior executives in industry** organised by the U.K.A.E.A. at Wantage. Information from U.K.A.E.A. Isotope School, Wantage Radiation Laboratories, Wantage.

SEPTEMBER 21 TO OCTOBER 1 **International Factory Equipment Exhibition** at Belle Vue, Manchester. Information from the organisers, Industrial & Trade Fairs Ltd., Drury House, Russell Street, Drury Lane, London, W.C.2.

SEPTEMBER 22 AND 23 Symposium on **the manufacture and use of some catalysts in the petroleum and petrochemical industries** at the Donnon Laboratories, Grove Street, Liverpool. Organised by the Liverpool section and Chemical Engineering Group of the Society of Chemical Industry. Details from Mr. J. H. Jarwood, Peter Spence & Sons Ltd., Widnes, Lancs.

SEPTEMBER 22 AND 23 Symposium on **the protection of gas plant and equipment from corrosion** at the College of Advanced Technology, Birmingham. Organised jointly by the college, the Institution of Gas Engineers and the Society of Chemical Industry, Corrosion Group. Details from department of chemistry of the college, Suffolk Street, Birmingham 1.

SEPTEMBER 22 TO 24 Conference on **the theory and practice of ultrasonic inspection** to be held at the Queens Hotel, Cheltenham. Organised jointly by the Institute of Physics' Non-Destructive Testing Group, the Society of Non-Destructive Examination and the Non-Destructive Testing Society of Great Britain. Details from the conference secretary, I. M. Barnes, Materials Laboratory, de Havilland Propellers Ltd., Hatfield, Herts.

SEPTEMBER 26 TO 28 Summer school on **the protection of metals by paints** to be held at Battersea College of Technology. Details from the summer school secretary, Battersea College of Technology, London, S.W.11.

SEPTEMBER 27 TO 28 Symposium on **automatic control** sponsored by the British Conference on Automation and Computation and arranged by the Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

SEPTEMBER 29 TO 30 Symposium on **powders in industry:** properties and principles of application, to be held at the Royal Institute, London. Organised by the Surface-activity Group of the Society of Chemical Industry, 14 Belgrave Square, London, S.W.1.

SEPTEMBER 29 Robert Horne Memorial Lecture to be delivered by Prof. F. D. Richardson in Bristol. Title: **The Extractions of Metals and the Chemistry of Melts.** Organised by the Society of Chemical Industry, 14 Belgrave Square, London, S.W.1.

OCTOBER 3 TO 7 **Brewers' and Allied Trades'** Exhibition at Olympia. Details from the organisers, Trades, Markets & Exhibitions Ltd., Grand Buildings, Trafalgar Square, London, W.C.2.

OCTOBER 4 TO 7 Conference on **synthetic rubber and synthetic fibres for the rubber industry** at the Berlin Congress Hall. Details from the organisers, Deutsche Kautschuk-Gesellschaft der Bunawerke Huls GmbH., M. Marl, Kreis Recklinghausen, Western Germany.

OCTOBER 11 TO 14 Symposium on **inelastic scattering of neutrons in solids and liquids,** to be held in Vienna. Details from the organisers, I.A.E.A., 11 Kartner Ring, Vienna 1, Austria.

OCTOBER 18 TO 21 **Effluent and Water Treatment** Exhibition and Convention at the Symour Hall, London, W.1. Details from the organisers, Thunderbird Enterprises Ltd., 140 Cromwell Road, London, S.W.7.

OCTOBER 23 TO 30 Thirty-second **Congres International de Chimie Industrielle** in Barcelona. Details from the organisers, Chimie et Industrie, Soprodoc, 28 Rue Saint-Dominique, Paris 7.

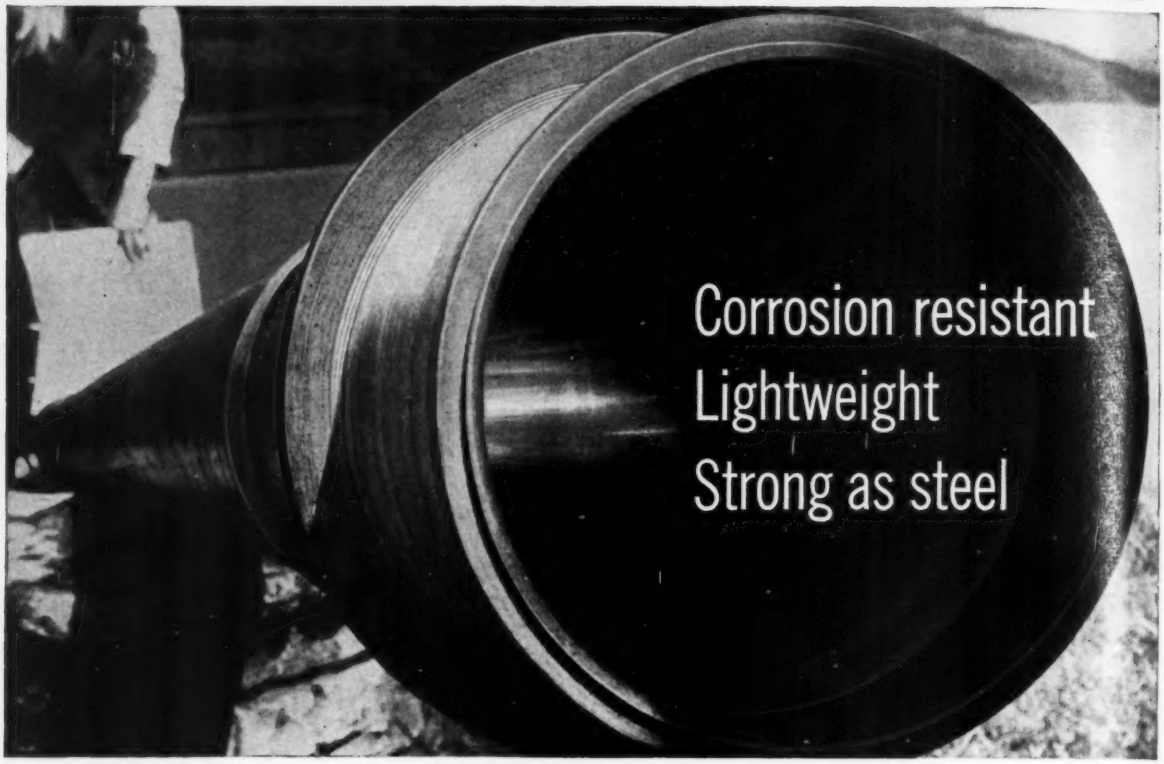
OCTOBER 24 TO 27 Symposium on **chemical effects of nuclear transformations** in Prague. Organised by International Atomic Energy Agency, Vienna.

OCTOBER 29 TO NOVEMBER 7 Standard course on **reactor technique** at the Harwell School. Details from the principal, Reactor School, A.E.R.E., Harwell, Didcot, Berks.

NOVEMBER 8 TO 10 Conference on **non-destructive testing in electrical engineering.** Details from the organisers, the Institution of Electrical Engineers, Savoy Place, London, W.C.2.

NOVEMBER 29 TO DECEMBER 2 **The Corrosion and Metal Finishing Exhibition** to be held at Olympia. Organised by Leonard Hill Ltd. Details from the Director, the Corrosion and Metal Finishing Exhibition, 9 Eden Street, London, N.W.1.

BRISTOL PIPE



Bristol Plastics have developed a range of high-precision pipes which has a wide variety of heavy-duty applications. Wherever problems of corrosion or weight interfere with efficient pumping or installation, Bristol pipes offer many big advantages over conventional steel piping.

Bristol Pipe Construction

Bristol pipes are made up of immensely strong helical windings of glass cords embedded in epoxide resin and lined with an abrasion-resistant synthetic fibre matrix which has a glass-smooth surface. Bristol pipes can be manufactured at present in any size from a 6-inch to a 15¼-inch bore, and production techniques are being developed to increase the available bore diameters to 3 feet.

Bristol Pipe Properties

Bristol pipes are highly resistant to corrosion. They need no protective sheathing and can handle liquids, including dilute acids and other corrosive chemicals at high pressures up to 600 psi and above, and up to 140° C.

Bristol Pipe patented couplings.

Bristol pipes are *only one quarter the weight of steel* yet they have the same tensile strength as steel piping and can withstand the same degree of abrasion. Being very light, they can be assembled in prefabricated sections which require no special handling equipment. In fact, three men, using Bristol patented couplings, can install or lay 200 ft of 6-inch pressure pipe per hour!

As the pipe bore is glass smooth, flow characteristics are extremely good. And this means that less pumping equipment and smaller-diameter pipes can be used for the same bulk flow.

Bristol Pipe Applications

Bristol pipes have been specially designed for conditions where steel piping corrodes, where installation costs are high, or where prefabricated systems can be used to advantage. Bristol pipes are particularly suitable for chemical plants, oil-well installations and natural-gas pumping stations, and for many other similar applications.

Enquiries should be addressed to:—**Sales Department, Bristol Aeroplane Plastics Limited, Filton, Bristol, England.**

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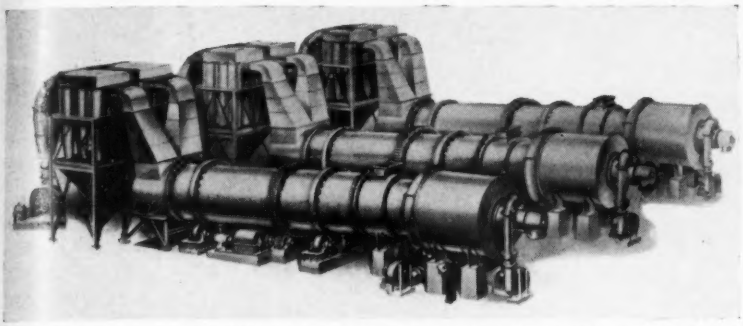
Orders and Contracts



An artist's impression of the rotary driers installed at the Redbourne Works of Richard Thomas & Baldwins Ltd.

Iron ore drying plant

Six rotary driers for an iron ore drying plant costing about £240,000 are to be supplied to Richard Thomas & Baldwins Ltd. to Head Wrightson Stockton Forge Ltd. Each installation is capable of handling a weekly output of 21,350 tons of ore processing from 0 to 2.5 in.

The rotary driers are arranged in parallel flow and each have a rated capacity of 50 tons/hr. when drying from 20% moisture down to 9%. The efficiency of the dust collectors is said to be such that with an inlet dust content of 18 to 20 gr./cu.ft. gas the outlet dust content would be no more than 1 gr./cu.ft.

Radioactive chemical processing

Collaboration and licence agreements have been signed between the U.K.A.E.A. and two chemical engineering companies to help British industry to compete for export business in the design and manufacture of radioactive chemical-processing plant.

The two companies are W. F. Fraser & Co. Ltd. and Nuclear Plant Ltd. These agreements are the result of the Authority's decision to collaborate with members of the British chemical engineering industry who desired to enter the nuclear chemical field.

The agreements cover plant and processes connected with the production of uranium metal billets from uranium ore concentrates and the reprocessing of irradiated nuclear fuel elements.

Under the agreements, the Authority provides, in return for royalties:

(*a*) A non-exclusive licence to the companies under the Authority's wide patent cover in the nuclear chemical field.

(*b*) General advice on technical problems.

(*c*) Assistance in commissioning and specialised training relating to the particular plants to be built by the companies.

(*d*) Further training, when required, of the companies' staff.

(*e*) Information on current and future significant work in the field.

Billet mill

The Head Wrightson Machine Co. Ltd. have received an order from Maschinenfabrik Sack GmbH., of Dusseldorf, for the provision of equipment for a complete billet mill. The value of the contract is about £700,000 and includes the intermediate roller tables, cooling banks and mill drives.

The equipment is to be installed at the Redbourn works of Richard Thomas & Baldwins Ltd., from whom Sack have received a contract for the supply of the complete mill.

The manufacture of the plant will be completed at the Middlesbrough and Thornaby works of Head Wrightson.

Rubber drying equipment

John Dalglish & Sons have been awarded the contracts valued at £250,000 for the synthetic rubber drying equipment to be used in the first factories of this kind to be erected in Brazil and in Australia.

The equipment for Brazil—four three-tier rubber driers—is for a refinery near Rio de Janeiro, operated by Petrobas, the State-controlled enterprise.

The two large driers to be supplied for the refinery installation near Melbourne have been ordered by Standard-Vacuum Oil Co. of New York.

Acetic acid plant

The Lummus Co. Ltd. have been appointed by the Distillers Co. Ltd. to carry out the mechanical design, procurement and supervision of construction of a £2 million acetic acid plant at Hull, which will come into operation early in 1962.

The new plant will use a new process developed by Distillers' Research and Development Department based on the direct oxidation of a light petroleum fraction.

Acrylic fibres

Courtaulds Ltd. and Luna Ltd., a wholly-owned subsidiary of Courtaulds, have entered into a contract with Acetilen of Skopje, Invest-Import, Belgrade, and Vardar Export-Import, Skopje, whereby Luna will supply plant and machinery for a factory in Yugoslavia to produce acrylic fibre. The value of the contract exceeds £2 million.

Deliveries of plant will begin next year and the factory will be in operation in 1962.

Automatic analytical control instruments

Elliott-Automation Ltd. have entered into an agreement with Hallikainen Instruments, of Berkeley, Calif., U.S.A., under which they will exploit the range of automatic analytical control instruments developed by the Shell Research Laboratories at Emeryville, Calif., for the petroleum, petrochemical and chemical industries and manufactured under licence by Hallikainen. Hallikainen Instruments will supply the North and South American markets and Japan with these instruments and Elliotts the rest of the world.

The instruments covered by the agreement are mainly for the 'in-line' control of processes by continuous measurement of viscosity, vapour pressure, distillation points, specific gravity and colour analysis.

This type of equipment is used in advanced automation systems to control processes directly by means of continuous automatic analysis of the quality of the material being processed.

Land for expansion

Pfizer Ltd. have purchased the Richborough Port, Sandwich, Kent. The area of land involved—which adjoins the company's present 80-acre site—is about 89 acres. The land will be used for the company's future development of its manufacturing needs in its various fields of interest, which include chemical, pharmaceutical and agricultural products.

Personal Paragraphs

★ **Dr. R. L. P. Berry,** beryllium project manager since 1958, has been appointed to the board of I.C.I. metals division. He has also been appointed to the delegate boards of two I.C.I. subsidiary companies, Marston Excelsior Ltd. and Lightning Fasteners Ltd.

★ **Mr. J. Linnell** has been appointed assistant sales manager of Q.V.F. Ltd. He will retain his position as personal assistant to the sales director.

★ **Mr. A. D. Wilson** has been appointed to the board of John & E. Sturge Ltd. He will continue to be general manager of the company's works at Selby which is concerned mainly with the production of citric acid by the industrial mould fermentation process.

★ **Mr. J. L. Orme** has been appointed deputy chief engineer for the London, eastern and southern areas of G.E.C. Ltd. He joined the company as an apprentice in 1920.

★ Owing to the pressure of his other business interests **Sir Graham Hayman** has relinquished the chairmanship of B.T.R. Industries Ltd., but retains his seat on the board. **Sir Walter Worboys** has been elected as chairman of the company.

★ At his own request, **Sir William Garrett** relinquished his executive responsibilities with Monsanto Chemicals Ltd., in order to devote more time to his other interests. He will continue as a member of the board. Since 1957 Sir William held, among other executive activities, the position of personnel director of the company. These duties will now be assumed by **Mr. N. F. Patterson,** director in charge of engineering and purchasing. Sir William is chairman of the Association of British Chemical Manufacturers and a director of Metal Industries Ltd. He is a member of the Civil Service Arbitration Tribunal. He was president of the British Employers' Confederation from March 1958 until March 1960.

★ **Mr. L. N. Borra** has been appointed to the board of directors of T. Giusti & Son Ltd. in the position of works director.

★ The following appointments were made in Head Wrightson & Co. Ltd. subsidiary companies: **Mr. J. G. Allen** has become managing director of Head Wrightson Steel Foundries Ltd.; **Mr. G. Jones** has been appointed managing director of Head Wrightson Stampings Ltd.; **Mr. W. H. Mather** has been appointed managing director and **Mr. G. Gowthorp** as commercial director of the Head Wrightson Machine Co. Ltd.; and **Mr. T. H. Stayman** has been appointed managing director of Head Wrightson Iron and Steel Works Engineering Ltd.

★ Nordac Ltd., one of the Woodhall-Duckham group of companies, has reconstructed the board of directors. **Dr. H. Hollings,** O.B.E., has been elected chairman and **Mr. J. Bishop** reappointed managing director. **Mr. A. E. Norman** remains on the board and **Mr. J. Austin** has been appointed technical director.

Mr. L. N. Borra.

Mr. J. G. Allen.

★ **Mr. F. A. Lyne,** hon. secretary of the Association of Public Analysts, has joined the consulting practice of J. A. Radley as head of the analytical section, but has retained his appointment as Public Analyst and Official Agricultural Analyst.

★ **Mr. A. J. C. Waters,** C.B.E., director and secretary of the British Man-made Fibres Federation since its setting up as the British Rayon Federation in 1943, is to retire in October.

★ **Mr. N. G. McCulloch,** C.B.E., has resigned as chairman of the British Cotton Industry Research Association (the Shirley Institute) and has been succeeded by **Mr. J. Lingley,** O.B.E.

★ **Mr. B. H. Turpin,** managing director of Q.V.F. Ltd. and of Quickfit and Quartz Ltd., has been elected to the Council of the British Chemical Plant Manufacturers' Association.

★ **Mr. J. E. Bishop** has been appointed general sales manager of the Pulsometer Engineering Co. Ltd. and Joseph Evans & Sons (Wolverhampton) Ltd.

★ **Mr. T. B. Adkins,** general manager of the ore mining branch of the United Steel Co. Ltd. for 13 years, retired in June after 56 years with the company. He is succeeded by **Mr. D. R. Ward Jones,** who was previously assistant general manager of the branch. **Lt.-Col. P. F. Benton Jones,** who is managing director (mining and carbonisation) of United Steel, relinquished the position of general manager of United Coke and Chemicals Co. Ltd. **Mr. A. L. Curtis,** operations manager of that company, became general manager of United Coke and Chemicals.

★ **Mr. K. P. E. Jeens** has been appointed manager of oil industries department of Worthington-Simpson Ltd. He was till recently with Stone & Webster Engineering Ltd., where he was pump and compressor engineer.

Mr. B. Branch, president of Dow International (*centre*) **is seen here with Dr. W. Ripper of Dow Agrochemicals and Mr. Leonard Hill** (*on his right*) **and with Dr. R. de B. Ashworth of the Ministry of Agriculture, Fisheries and Food, and Mrs. J. Jones of Isis Appointments Register** (*on his left*)**, at a reception given by Dow International.**

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